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STATE OF MONTANA
NATURAL RESOURCE DAMAGE PROGRAM

BUTTE GROUNDWATER INJURY ASSESSMENT REPORT
UPPER CLARK FORK RIVER NPL SITES

JANUARY 1995



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**BUTTE GROUNDWATER INJURY ASSESSMENT REPORT
CLARK FORK RIVER BASIN NPL SITES, MONTANA**

**STATE OF MONTANA
NATURAL RESOURCE DAMAGE LITIGATION PROGRAM**

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JANUARY 1995



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ACRONYMS

AMD	Acid Mine Drainage
ARCO	Atlantic Richfield Company
ASARCO	American Smelting and Refining Company
BMP	Bedrock Monitoring Program
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFRSSISOP	Clark Fork River Superfund Site Investigation Standard Operating Procedures
CFS	Cubic Feet per Second
ICP - MS	Inductively Coupled Argon Plasma - Mass Spectrometry
ICP - AES	Inductively Coupled Argon Plasma - Atomic Emission Spectrometry
LAO	Lower Area One
MBMG	Montana Bureau of Mines and Geology
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MDHES	Montana Department of Health and Environmental Sciences
MGD	Million Gallons per Day
MPC	Montana Power Company
MR Concentrator	Montana Resources, Inc. Concentrator (formerly the Weed Concentrator)
MSD	Metro Storm Drain
MSTP	Metro Sewerage Treatment Plant
NRDA	Natural Resource Damage Assessment
OU	Operable Unit
QA/QC	Quality Assurance/Quality Control
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of Decision
SDWA	Safe Drinking Water Act
SMCL	Secondary Maximum Contaminant Level
USGS	United States Geological Survey

EXECUTIVE SUMMARY

Introduction

Groundwater injury in two operable units of the Silver Bow Creek Superfund site, the Butte Mine Flooding Operable Unit (OU) and the Area I Operable Unit,¹ are examined in this report.

Two types of aquifers are located in the study area: alluvial and bedrock. Groundwater in the bedrock aquifer occurs predominantly within fractures, joints, faults and in the underground mine workings. The upper 200 to 300 feet of the Butte quartz monzonite in the Butte Hill area bedrock aquifer is highly weathered and fractured. The alluvial aquifer comprises semi-consolidated Tertiary and Quaternary valley fill deposits that overlie weathered bedrock along Silver Bow Creek, the Metro Storm Drain (MSD), the Montana Resources (MR) Concentrator area, and the area to the southeast and east of the Berkeley Pit in the vicinity of the leach pads.

A large cone of depression exists around the Berkeley Pit as a result of pumping activities. Groundwater flow direction in the bedrock aquifer is toward the pit in all areas within the cone of depression. Groundwater flow patterns in the alluvial aquifer are also influenced by the cone of depression surrounding the pit. A groundwater divide exists between the Continental Pit and the Metro Storm Drain near the MR Concentrator. Groundwater north of the divide flows into the Berkeley Pit, while groundwater south of the divide flows parallel to and toward the Metro Storm Drain and Silver Bow Creek.

Sources of Groundwater Contamination

Gold was discovered in the Butte area in 1864. Mining and processing of gold, silver and copper ore has continued in one form or another (placer, underground, open pit, and leaching operations, smelting) to the present day.

The sources of groundwater contamination in the Butte Mine Flooding OU are: the underground workings; the walls of the Berkeley and Continental Pits; mine water in the underground workings; waste rock and tailings piles near the Berkeley Pit; leaking solutions from the leach pad and the Weed/MR Concentrator areas; leaking solutions from the Yankee Doodle Tailings Pond; contaminated soils and alluvium; and sulfuric acid added to the underground mines for copper leaching.

The sources of groundwater contamination in the Area I OU are: the buried Parrott tailings; slag, mill and other wastes around the historic Parrott Smelter and the City-County Shop

¹ Area I OU has been incorporated into the Butte Priority Soils Operable Unit.

Complex; manganese stockpiles and manganese flue dust in the manganese stock pile/Butte Reduction Works area (removed in 1992); surficial and buried tailings disposed of along the MSD and Silver Bow Creek; the Butte Reduction Works tailings impoundments (partially removed in 1994); the historic Colorado Smelter; railroad ballast; efflorescent salts on tailings piles and along the banks of Silver Bow Creek; streamside tailings along Silver Bow Creek and the Metro Storm Drain; contaminated soils; mixed contaminated soils/alluvial material and tailings throughout Area I, the Colorado Tailings, and mine water and process water discharged to Silver Bow Creek/MSD.

Identity of Hazardous Substances and Relevant Standards

The hazardous substances identified in source materials were: antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, vanadium, zinc, sulfuric acid, and sulfides of several of these hazardous substances (copper, arsenic, zinc, lead, silver, antimony). In addition to the hazardous substances identified in sources of groundwater contamination, some substances are not listed as hazardous under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), yet are a result of mining operations in the study area. Acid mine drainage produced as a result of the release of hazardous substances will leach other sulfides and aluminosilicates in source materials in the study area and produce high concentrations of iron, manganese, aluminum, sulfate, metals, and metalloids. Although sulfate, iron, manganese, and aluminum are not listed as hazardous substances under the CERCLA, they do result from the release of hazardous substances. In addition, ferric sulfate and aluminum sulfate, which are both constituents of acid mine drainage, are listed as hazardous substances under CERCLA. Therefore, iron, manganese, sulfate, and aluminum are included in the list of relevant substances for the study area. Any mention of hazardous substances in this report refers to hazardous substances and the relevant related substances iron, manganese, aluminum and sulfate.

The relevant standards for groundwater injury in the study area are determined to be the primary drinking water standards (maximum contaminant levels [MCLs] and MCL goals [MCLGs]) and the secondary drinking water standards (secondary MCLs [SMCLs]) established under the Safe Drinking Water Act and relevant Montana statutes and regulations.

Pathway Determination

The principal pathways for groundwater contamination are: (1) leaching of hazardous substances in the unsaturated zone to downgradient groundwater via infiltration of surface runoff or rising capillary groundwater; (2) leaching of hazardous substances in the saturated zone via groundwater flow through sources or changes in groundwater level; and (3) transport of water containing hazardous substances (i.e., from leaking processing units or contaminated alluvial groundwater) through the unsaturated or saturated zone to downgradient groundwater, pit water and surface water.

Sources identified in the study area have been shown to leach substantial concentrations of hazardous substances to groundwater. Formation of acid mine drainage in the underground workings involves a similar leaching of primary source materials that generates substantial concentrations of dissolved sulfate, iron, aluminum and hazardous substances in minewater in the Butte Hill/Berkeley Pit area.

Sources of water containing hazardous substances include: (1) process solutions from the historic Weed Concentrator and the current MR Concentrator; (2) solutions associated with operation of the leach pads; (3) mine and process waters; and (4) contaminated alluvial and bedrock groundwater. These waters can be transported: (1) through the unsaturated zone to downgradient groundwater either in the alluvial or bedrock aquifers; (2) to the Berkeley Pit; and (3) to surface waters in the Metro Storm Drain and Silver Bow Creek.

It is apparent from the comparison of Berkeley Pit water chemistry with that of minewater and process inflow waters, that the range of minewater composition does not explain the observed chemistry of the pit water. Inflow of contaminated surface water and process water has had an effect on the composition of the pit water. Reactions involving the pit walls may also add hazardous substances to the Berkeley Pit water.

Wells completed in bedrock directly below the Colorado Tailings show extremely elevated concentrations of copper, zinc, sulfate and other hazardous substances. In this area, contamination from tailings has likely reached the bedrock aquifer. Directly downgradient of the Colorado Tailings, the alluvial aquifer groundwater discharges to and further contaminates Silver Bow Creek with hazardous substances.

The mobility of hazardous substances in aquifers is a complex function of hydrodynamic and biogeochemical processes and conditions, including recharge locations, infiltration rate, hydraulic gradient, groundwater velocity and flow patterns, discharge locations, permeability, solubility, precipitation, adsorption, desorption, oxidation/reduction, and other reactions. Some of the processes responsible for mobility of the identified hazardous substances are discussed in Section 2.2.3 of the report.

Maximum rates of transport for a number of hazardous substances were estimated for the alluvial aquifer groundwater plume in the vicinity of the Metro Storm Drain:

Sulfate	=	72.7 ft/yr
Zinc	=	63.6 ft/yr
Copper	=	62.5 ft/yr
Cadmium	=	61.4 ft/yr
Iron	=	45.5 ft/yr
Arsenic	=	19.9 ft/yr
Lead	=	14.2 ft/yr.

The above estimated transport rates are based on the farthest extent of the groundwater plume for each hazardous substance and the time since disposal of the source material (beginning of operation of the Parrott smelter). It is also possible that the discharge of untreated minewater to the MSD contributed to the extent and concentration of hazardous substances in the groundwater plumes. The midpoint of application of untreated minewaters would be later than 1900, and if the discharges contributed to the plumes, transport rates for hazardous substances would be shorter than those shown above.

Baseline Conditions

The following criteria were established to determine baseline groundwater conditions in the alluvial and bedrock aquifers:

- ▶ Similar geology to that of impacted areas
- ▶ Similar groundwater flow patterns and system to those of impacted areas
- ▶ Location of baseline wells away from obvious sources of hazardous substances and associated plumes
- ▶ Consideration of groundwater type and other geochemical indicators that may distinguish uncontaminated from contaminated groundwater.

Bedrock Aquifer

Baseline water quality from wells in the bedrock aquifer were initially divided into three categories based on the location of the wells relative to the mineralized and unmineralized portions of the bedrock aquifer and whether or not the wells were completed in weathered or unweathered (competent) bedrock:

- ▶ Unmineralized
- ▶ Weathered/mineralized
- ▶ Unweathered/mineralized.

Median concentrations in the unmineralized, weathered/mineralized, and unweathered/mineralized groundwaters did not exceed any MCL values. However, median concentrations exceeded three SMCL values in the unweathered/mineralized baseline wells: iron, manganese, and sulfate. The median sulfate concentration in the weathered/mineralized wells also exceeded the sulfate SMCL. The unmineralized samples generally had the lowest mean concentrations, while the unweathered/mineralized samples generally had the highest mean concentrations.

The groundwaters in the central ore zone are considered to be at least somewhat impacted by mining, and may have naturally-occurring elevated concentrations of some constituents. Elevated concentrations of sulfate (from formation of acid mine drainage under oxidizing conditions) in the unweathered/mineralized portion of the aquifer are more likely related to mining impacts, such as addition of sulfuric acid for underground leaching of copper. The groundwater sampled in the central ore zone samples has acquired sulfate along its flow path from traveling through the oxidized portions of the mineralized zone, which have been increased as a result of dewatering activities. Apparently the acquired sulfate is not currently being reduced within the unweathered mineralized portion of the bedrock aquifer in Butte Hill. Baseline bedrock groundwater quality will be represented by median concentration values [43 CFR § 11.72 (h)(5)]. The wells have been combined to represent overall baseline quality of the aquifer as a whole, including the wells that may be somewhat impacted by mining in the central ore zone. No median concentration exceeded either an MCL or SMCL value.

In the injured bedrock wells, the MCL value for cadmium (5µg/l) was exceeded, and SMCL values for iron, manganese, pH, zinc, and sulfate were also exceeded.

Median concentrations and p-values for the comparison of baseline and injured bedrock groundwater are presented in Table ES-1. All substances of concern with median concentrations that exceeded relevant standards in injured bedrock groundwater had statistically significant p-values when compared to median concentrations of these substances in baseline or control bedrock groundwater, which indicates that there is a statistically significant difference between baseline and injured bedrock groundwater.

Alluvial Aquifer

In the alluvial aquifer control wells, one of three samples from well GS-20 exceeded the thallium MCL; however, the other two samples for this well taken within one year of the first sample did not show that the thallium MCL value (2 µg/l) was exceeded. Median concentrations for the alluvial control well samples show that no other MCL or SMCL exceedences in the baseline alluvial groundwater (Table ES-2).

There were two injured alluvial aquifer areas: Area I and Butte Hill. Median concentrations exceeded MCL values for cadmium, and thallium and SMCL values for manganese, zinc, and sulfate in the Area I wells (Table ES-2). Median concentrations exceeded MCL values for cadmium and SMCL values for copper, manganese, zinc, sulfate, and TDS in the Butte Hill wells.

Table ES-2 also shows p-values for the Area I and Butte Hill wells as compared to baseline alluvial aquifer wells. In Area I, all substances that have median concentrations exceeding relevant standards have significant p-values when baseline and injured concentrations are compared. In the Butte Hill alluvial aquifer, for substances that do exceed relevant standards,

Table ES-1
Bedrock Aquifer
Comparison of Baseline and Injured Areas: Median Concentrations ($\mu\text{g/l}$; SO_4 in mg/l)
and Two-Sided p-Values

Analyte	Baseline	Injured	p-Value
Ag	1.96	30.65	0.0005
Al	24.5	20	0.4675
As	3.13	28.6	0.0016
Cd	1.02	9.5	0.0017
Cr	3.01	2.5	0.1611
Cu	8.5	25	0.0374
Fe	40	4,640	0.0019
Mn	45.1	2,400	0.0016
Ni	6.9	356	0.0005
pH	7.06	6.1	0.0002
SO_4	174	948	0.0001
Zn	80.5	16,200	0.0026

Source: Appendix II.

only manganese does not show a statistically significant difference between baseline and injured wells when compared using the Mann-Whitney test (Table ES-2).

Extent of Injured Groundwater

Bedrock Aquifer

A substantial portion of injured water associated with the bedrock aquifer is in the Berkeley Pit. Berkeley Pit water exceeded primary and/or secondary drinking water standards for pH, sulfate, TDS, fluoride, iron, manganese, aluminum, arsenic, cadmium, copper, nickel, lead, and zinc. Bedrock groundwater in the Butte Hill area exceeded MCL and SMCL values for pH, sulfate, TDS, aluminum, arsenic, cadmium, copper, iron, fluoride, lead, manganese, nickel, and zinc.

Table ES-2
Alluvial Aquifer
Comparison of Baseline and Injured Areas: Median Concentrations and p-Values
($\mu\text{g/l}$; SO_4 in mg/l)

Analyte	Baseline	Area I		Butte Hill	
	Median	Median	p-Value	Median	p-Value
Al	9.4	157	0.0070	210	0.0164
As	1.6	4.4	0.0457	.95	0.4929
Cd	.55	23.8	0.0002	44.1	0.0003
Cr	3.45	4	0.0255	2	0.9379
Cu	3.75	90.5	0.0079	1,080	0.0002
Fe	54	98	0.3750	39.5	0.9287
Mn	33	11,000	0.0016	166	0.4835
Ni	1.58	8.9	0.0189	57.4	0.0005
Ag	0.5	ND	ND	1	0.0060
Zn	85	7,200	0.0002	8,520	0.0002
SO_4	149	541	0.0006	810	0.0007
Be	.5	0.5	NC	ND	ND
* not computed NC not calculated ND Not determined Source: Appendix III.					

The areal extent of contaminated bedrock aquifer groundwater in the Butte Hill area is 2.01×10^8 square feet (7.22 square miles or 4,620 acres). At the action level (5,410 feet), the volume of water in the Berkeley Pit is estimated to be $8.56 \times 10^9 \text{ ft}^3$ (1.96×10^5 acre-feet or 64 billion gallons) (U.S. EPA, 1994). The volume of pit water at the action level is added to the volume of injured bedrock aquifer groundwater below the action level for a total of $1.43 \times 10^{10} \text{ ft}^3$ (327,000 acre-feet or 107 billion gallons) of injured bedrock groundwater in the Butte Mine Flooding area at the action level. The yield of the injured bedrock groundwater is estimated at 6,900 gpm or 1,300,000 ft^3/yr or 11,100 acre-feet/yr.

Alluvial Aquifer

Area I: The following contaminants were elevated in alluvial groundwaters above their MCL/SMCL values in two or more wells placed ≥ 100 feet apart: aluminum, antimony, beryllium, chromium, fluoride, manganese, nickel, thallium, copper, zinc, arsenic, cadmium, lead, iron, and sulfate.

The groundwater plume in the Metro Storm Drain area extends ≥ 10 to 40 feet below the water table in the downgradient direction toward the confluence of the MSD with Silver Bow Creek. The ordering of decreasing area of injured alluvial groundwater (based on areas for each hazardous substance that exceed MCL/SMCL values both east and west of Montana Street) is:

sulfate > cadmium > zinc > iron > lead > copper > arsenic.

The total areal extent of alluvial groundwater contaminated with hazardous substances in Area I is 2.45×10^7 square feet (0.88 square miles or 563 acres).

The largest plume was the sulfate plume, which had a volume of 4.34×10^8 cubic feet (9,960 acre-feet or 3.25 billion gallons). The cadmium plume was the second largest plume and had a volume of 3.69×10^8 cubic feet.

The ordering of decreasing volume of injured alluvial groundwater in Area I is:

sulfate > cadmium > zinc > iron > copper > lead > arsenic.

The net groundwater discharge exiting the Butte Basin is estimated as the sum of the alluvial aquifer discharge (0.053 cfs) and the net surface water discharge (3.25 cfs), or 3.30 cfs (1,480 gpm or 2,390 acre-ft/year or 104,000,000 ft³/yr).

Butte Hill: Zinc, copper, iron, lead, cadmium, and sulfate concentrations exceeded relevant water quality standards in groundwater in the Butte Hill alluvial aquifer. The water quality standard for zinc was exceeded in every well; the water quality standard for lead was exceeded in only two wells. Sulfate concentrations exceeded the SMCL value (250 mg/l) in all but one well (LP10).

The areal extent of injured groundwater in the Butte Hill alluvial aquifer is given by the extent of the zinc plume (the zinc SMCL was exceeded in all wells), which is 2.20×10^7 ft² (0.79 mi² or 505 acres)

The volumetric extent of injured alluvial groundwater in the Butte Hill area at 20% porosity is 4,850 acre-feet (2.12×10^8 ft³), as represented by the sulfate plume. The volumetric extent of the cadmium plume (4,830 acre-feet) is only slightly less than that for sulfate. The average

flux of injured alluvial groundwater in the Butte Hill area is given by the flux of the largest plumes, zinc, sulfate, cadmium, and copper, which are 17,900 ft³/day (150 acre-ft/yr). This represents flux through the central portion of the Butte Hill alluvial aquifer.

A summary of the areal and volumetric extent and flux of all injured groundwater in the study area is presented in Table ES-3.

Table ES-3 Summary of Areal and Volumetric Extent and Flux of Injured Groundwater in Area I and Butte Mine Flooding Operable Units			
Aquifer Type and Location	Areal Extent	Volumetric Extent	Flux or Yield
Bedrock Butte Hill	2.01 × 10 ⁸ ft ² 7.22 mi ² 4,620 acres	1.43 × 10 ¹⁰ ft ³ 327,000 ac-ft 107 billion gallons	6,900 gpm 1,330,000 ft ³ /yr 11,100 ac-ft/yr
Alluvial Area I	2.45 × 10 ⁷ ft ² 0.88 mi ² 563 acres	4.34 × 10 ⁸ ft ³ 9,960 ac-ft 3.25 billion gallons	1,480 gpm 104,000,000 ft ³ /yr 2,390 ac-ft/yr
Alluvial Butte Hill	2.20 × 10 ⁷ ft ² 0.79 mi ² 505 acres	2.12 × 10 ⁸ ft ³ 4,850 ac-ft 1.59 billion gallons	17,900 ft ³ /yr 150 ac-ft/yr
Total	2.48 × 10 ⁸ ft ² 8.89 mi ² 5,690 acres	1.50 × 10 ¹⁰ ft ³ 342,000 ac-ft 112 billion gallons	105,000,000 ft ³ /yr 13,600 ac-ft/yr

Recoverability

Recoverability is defined in this report as the time estimated for the groundwater resource to recover to baseline concentration levels if no additional remediation or restoration efforts are taken. Potential immobilization and mobilization mechanisms that will affect the extent of contaminated groundwater over time are discussed.

Assuming that the remaining hazardous substance sources that contaminate groundwater will not be removed, hazardous substances will continue to be transported in area groundwaters and thereby increase the size of contaminant plumes, especially in the upper MSD area. In Lower Area I, groundwater discharge to Silver Bow Creek limits the lateral extent of groundwater contamination, but the extent of contamination with depth may increase over time.

Sulfide minerals in source areas can be expected to leach lesser quantities of metals, metalloids, and sulfate to the unsaturated zone and groundwater over time as hazardous and related substances in these minerals are eventually exhausted by leaching mechanisms. This scenario depends on a number of geochemical and hydrodynamic factors, including consistent or overall oxidizing conditions in the source materials (buried tailings, etc.), availability of infiltrated water, sufficient hydraulic conductivities, etc. The production of sulfate from pyrite in mine wastes has been predicted to decrease exponentially in the first 50 to 100 years but not approach zero sulfate production until between 250 to over 350 years from the time of deposition of the wastes. At this future time the sources may have exhausted their ability to generate acid, but downgradient groundwater would still be injured with sulfate, metals and metalloids.

It can be assumed that hazardous substance sources in the study area will continue to adversely affect alluvial and bedrock aquifer groundwater and Berkeley Pit water for thousands to tens of thousands of years, absent removal of sources or implementation of effective remediation or restoration techniques.

1.0 INTRODUCTION

1.1 SITE DESCRIPTION

Gold was discovered in the Butte area in 1864, and large-scale copper mining began around 1882. Mining and processing of gold, silver and copper ore has continued in one form or another (underground, open pit and leaching operations, smelting) to the present day. Mining and processing operations have resulted in heavy metal and other contamination in the Butte area. This report addresses groundwater resource injury in two sections of the Silver Bow Creek/Butte Area Superfund site located in and near the city of Butte, Montana (Figure 1-1). The site is part of the Clark Fork Superfund complex, which is the largest group of Superfund sites in the United States.

1.1.1 Overview of Operable Units and Features

Groundwater injury occurring principally in two operable units, the Butte Mine Flooding Operable Unit and the Area I Operable Unit, are examined in this report. Generally, these Operable Units together comprise the study area.

Butte Mine Flooding Operable Unit. The Butte Mine Flooding Operable Unit (Mine Flooding OU) extends from the Continental Divide on the east to Missoula Gulch on the west side and from the Yankee Doodle Tailings Pond on the northern side to Silver Bow Creek on the southern side (Figure 1-2). The major features in the Butte Mine Flooding OU are:

- ▶ Yankee Doodle Tailings Pond
- ▶ Leach pads area
- ▶ Waste rock dumps
- ▶ Precipitation plant
- ▶ Berkeley Pit
- ▶ Continental Pit
- ▶ MR Concentrator area (formerly the Weed Concentrator)
- ▶ Underground mine workings
- ▶ Silver Lake Pipeline.

The underground mining areas were separated into the East Camp and West Camp in the early 1960s by concrete bulkheads to reduce the volume of water that had to be pumped to keep the central underground mines working. The East Camp includes the Berkeley Pit, the Kelley, Anselmo, Belmont, Chester, Granite Mountain, Lexington and Steward mines, and associated underground mine workings. The West Camp includes the Emma, Ophir, and Travona mines (Canonie, 1992a). The Marget Ann, Missoula and Orphan Boy mines are considered to be in the Outer Camp. The major connected underground workings extend for

at least 3,000 miles (James, 1980, as referenced in U.S. EPA, 1994). Pumping occurred from the Kelley shaft in the East Camp and the Travona shaft in the West Camp. The majority of the Butte Mine Flooding OU features are displayed in Figure 1-3; the underground mine workings (with connections) are displayed schematically in Figure 1-4. A description of these features can be found in Table 1-1.

Area I Operable Unit. The Area I Operable Unit extends from below the MR Concentrator (formerly the Weed Concentrator) parallel to the Metro Storm Drain and Silver Bow Creek to the Colorado Tailings (Figure 1-5). The Colorado Tailings/Butte Reduction Works vicinity is referred to as Lower Area I. The main features of the operable unit are:

- ▶ The historic Parrott Smelter
- ▶ The exposed and buried Parrott and other Tailings (near and under the City-County Shop Complex area)
- ▶ The Metro Storm Drain, Silver Bow Creek and Blacktail Creek
- ▶ The Butte Reduction Works and Manganese Stockpile area
- ▶ Butte Reduction Works Tailings impoundments
- ▶ The historic Colorado Smelter
- ▶ The Colorado Tailings.

A Phase I Remedial Investigation (RI) was completed by MultiTech (1987), and a Draft Final RI was completed in August 1990 by CH₂M Hill/Chen-Northern (CH₂M Hill and Chen-Northern, 1990).

1.1.2 Geology of the Study Area

Bedrock. The mountains in the upper Silver Bow basin are composed predominantly of quartz monzonite, which is a silica-rich plutonic rock (rocks formed from subsurface magma) in the granite family that has roughly equal amounts of orthoclase (potassium) and plagioclase (sodium/calcium) feldspars (Jackson, 1970). These rocks are part of a granitic mass known as the Boulder Batholith, which extends southwesterly from Helena to the Big Hole River in Beaverhead county (Sales, 1913).



Figure 1-1. Site Map, Butte Area, Montana. Sources: Canonie, 1992a; CH₂M Hill and Chen-Northern, 1990.

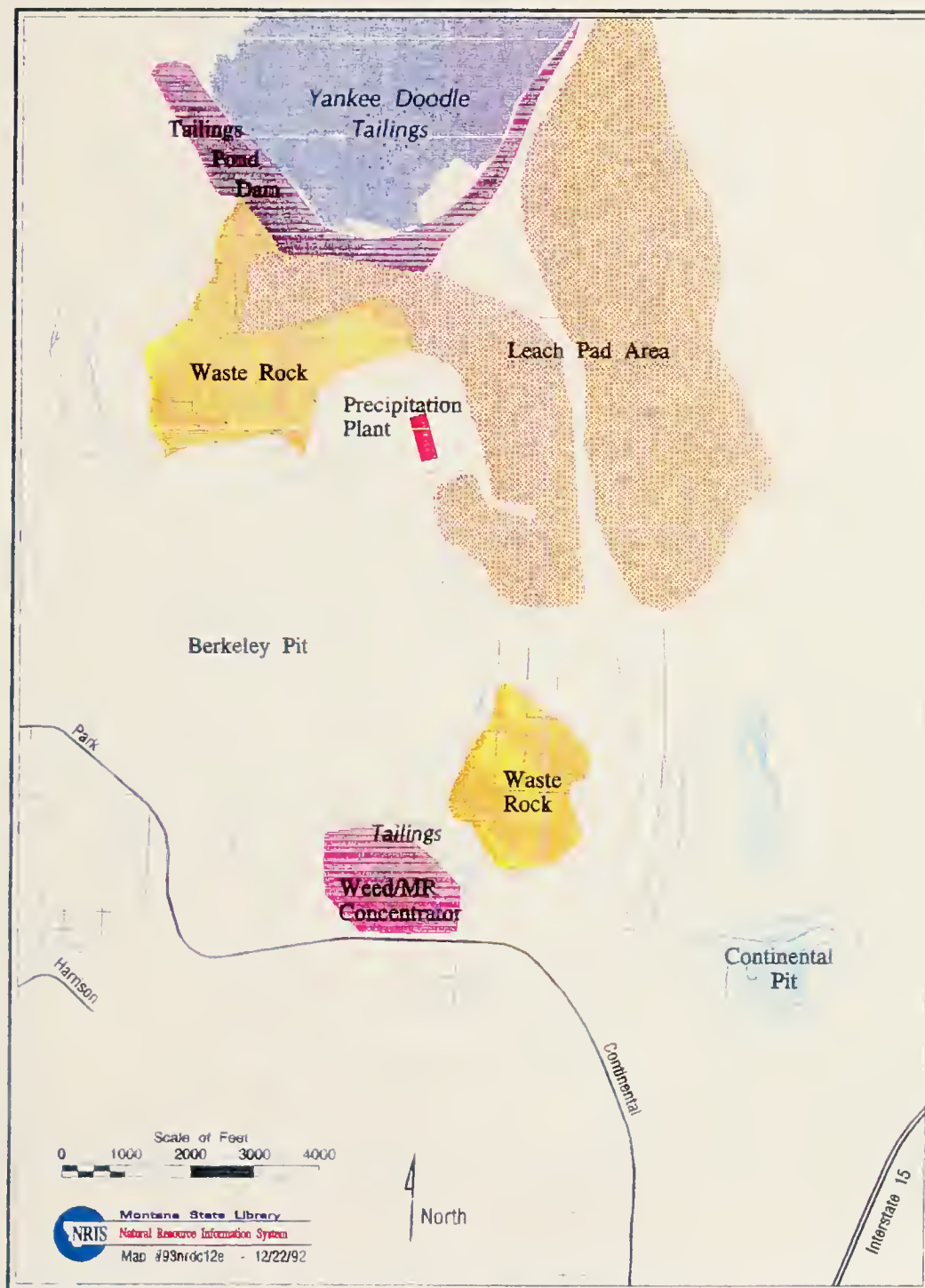


Figure 1-2. Butte Mine Flooding Operable Unit Features. Source: Canonie, 1992a.

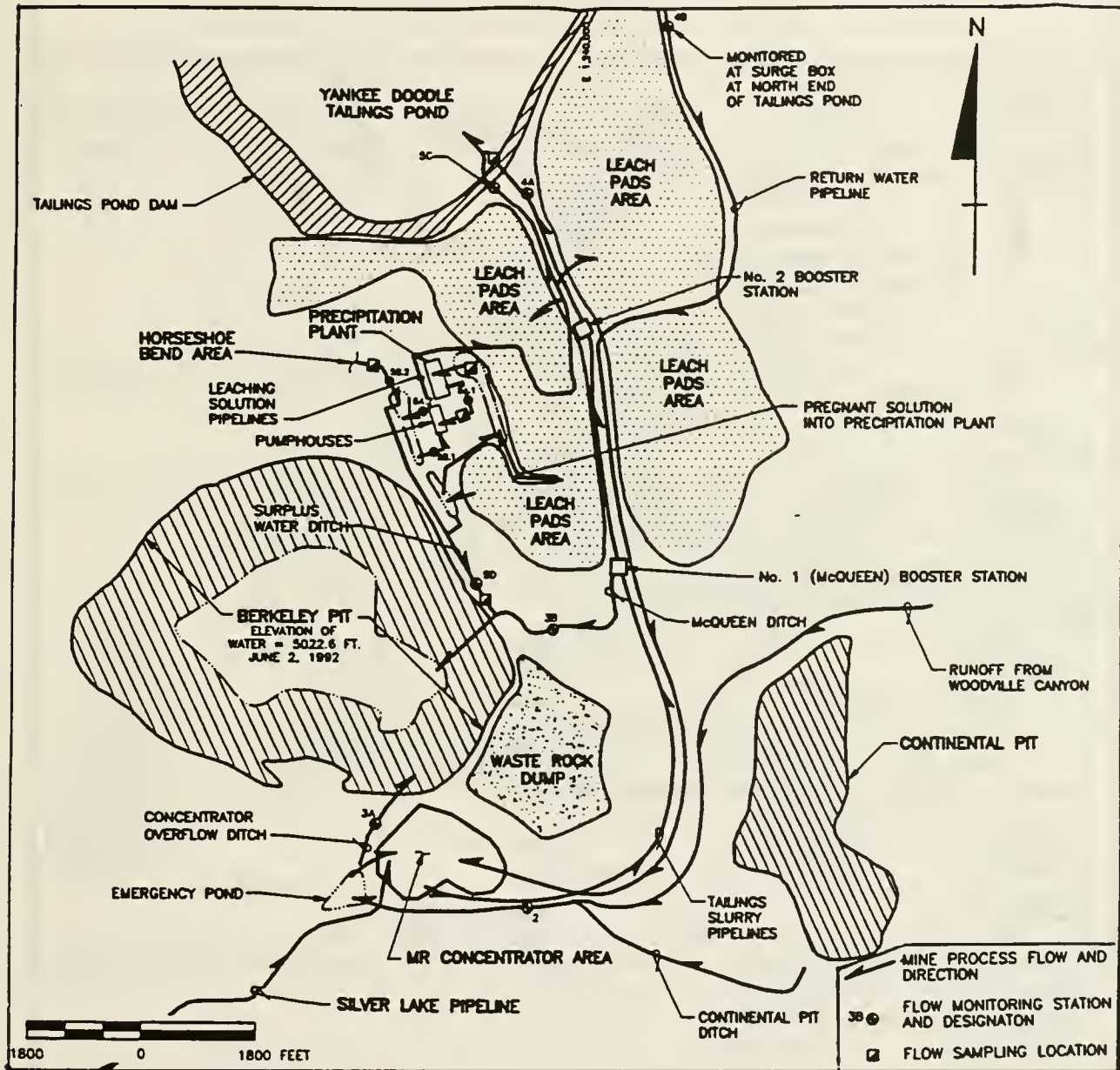


Figure 1-3. Butte Mine Flooding Operable Unit Process Flows and Units.

Source: Canonie, 1992a.

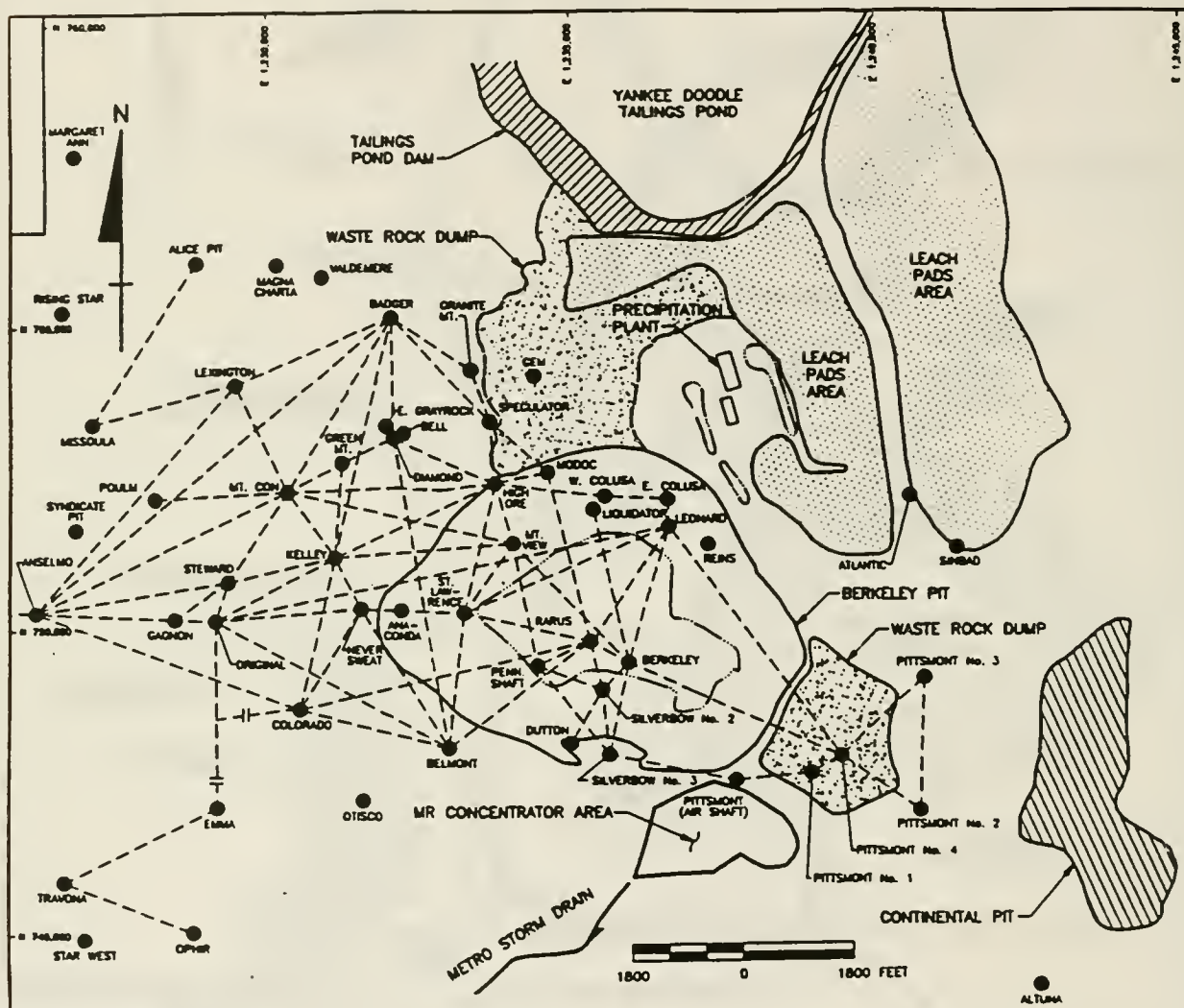


Figure 1-4. Map of Connected Underground Mine Workings. Source: Canonie, 1992a.

Table 1-1
Description of Units and Features in Butte Mine Flooding Operable Unit

Unit/Feature	Dimensions	Status	Description	Inputs/ Inflows	Outputs/ Outflows
Berkeley Pit	1780 ft. deep; 675 acres (1.06 mi ²); 1.18 × 10 ¹⁰ ft ³	Inactive	Open pit copper mine, now filling with water	Precipitation Plant surplus water; Upset flows from MR Concentrator and McQueen Booster Station; Minewater; Groundwater; Runoff; Precipitation	Evaporation
Continental Pit	~5,000 ft × 2,000 ft	Active	Open pit mine for low-grade copper-moly ore	Groundwater; Runoff; Precipitation	Pumped water → MR Concentrator
Leach pads area	9 unlined leach pads, 300 to 500 ft. thick, cover 10 to 120 acres each	7 Active pads; 2 Inactive pads	Leaching of low-grade ore and waste rock previously mined from Berkeley Pit	Leaching solution leaving Precipitation Plant (includes Horseshoe Bend seeps+sulfuric acid)	Pregnant solution from leach pads → Unlined Storage ponds → Precipitation Plant
MR concentrator (previously known as weed concentrator)	Processes 48,000 tons ore/day	Active	Mills ore from Continental Pit; produces copper and moly concentrates	Decant water from Tailings Pond; Water from Silver Lake Pipeline; Water pumped from Continental Pit	Copper and Moly concentrates; Tailings → Yankee Doodle Tailings Pond
Precipitation plant	Uses ~13 mgd water	Active	Precipitates copper on detinned iron scrap	Pregnant solution from leach pads; Horseshoe Bend seep water	Barren solution → Leach Pads or Tailings Pond

Table 1-1 (cont.)
Description of Units and Features in Butte Mine Flooding Operable Unit

Unit/Feature	Dimensions	Status	Description	Inputs/ Inflows	Outputs/ Outflows
Unlined storage ponds for Horseshoe Bend seep water and pregnant solution from leach pads	7 unlined storage ponds; 9.76 acres total	7 Active storage ponds	Hold make-up/surplus water for Precipitation Plant and pregnant solution from leach pads	Acidic seep water from Horseshoe Bend area; Pregnant solution from leach pads	Make-up water and pregnant solution → Precipitation Plant; Surplus Water → Berkeley Pit
Yankee Doodle Tailings Pond	750 Acres	Active	Settling basin for tailings slurry from Concentrator	Tailings slurry from MR Concentrator; Excess barren leach solution from Precipitation Plant; Runoff; Precipitation	Decant water → MR Concentrator; Groundwater seepage
Waste rock dumps	2 major dumps: N of pit; SE of pit	N dump Inactive; SE dump Active	Received/ receives waste rock and overburden from Berkeley and Continental Pits	Alluvial overburden and below economic grade bedrock from Continental Pit; Precipitation; Run-on	Infiltration → groundwater; Runoff
Mine shafts	Several thousand miles of inter-connected workings	Inactive	Abandoned underground workings mined for copper	Flooding groundwater	Flooding groundwater → Berkeley Pit
Metro storm drain	~8,000 ft in length	NA	Open channel ditch; Previously stretch of Silver Bow Creek	Stormwater runoff	Silver Bow Creek starts at confluence of Metro Storm Drain and Blacktail Creek

Sources: Canonie, 1992a; Canonie, 1992b; ARCO, 1994.

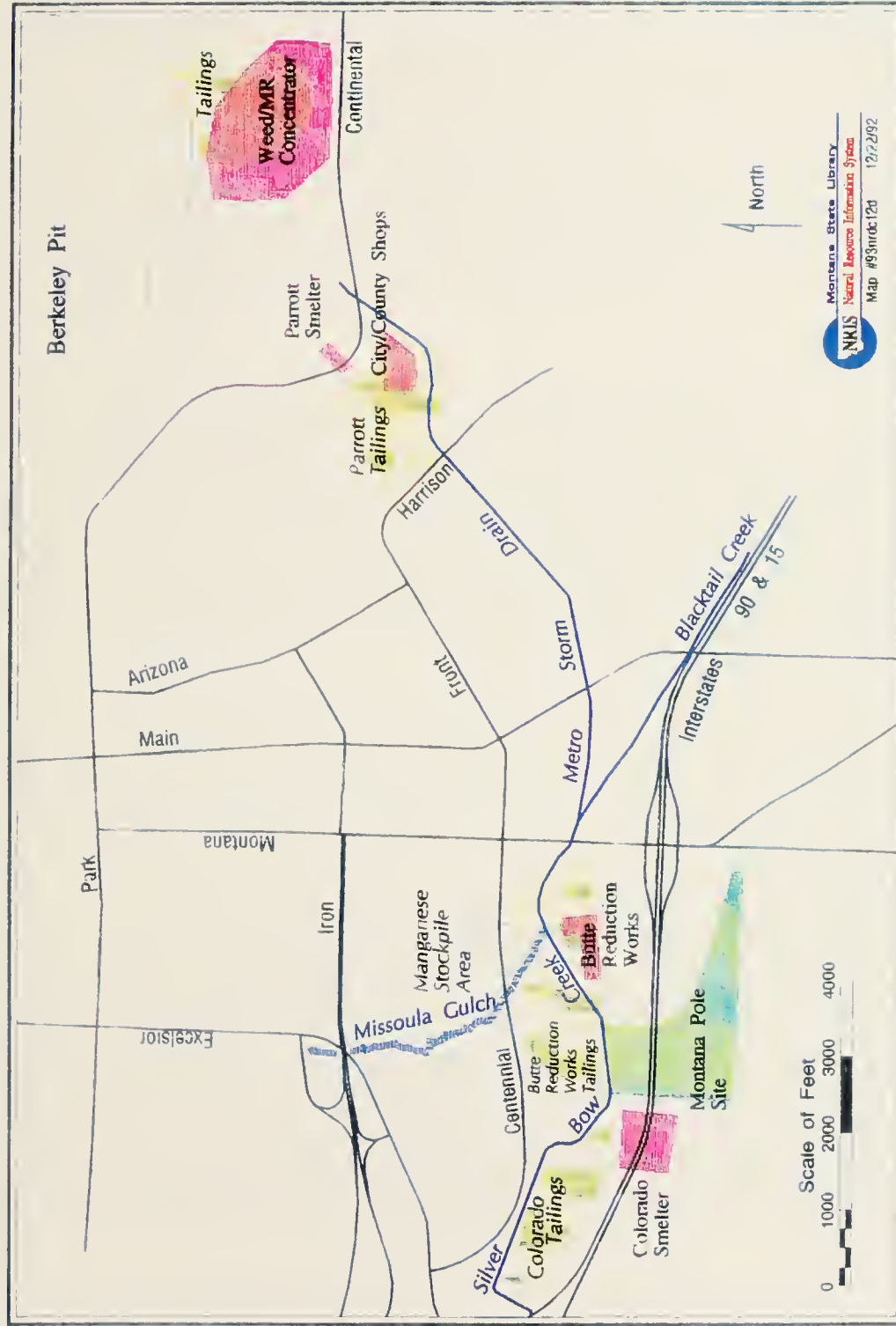


Figure 1-5. Area I Operable Unit Features. Source: CH₂M Hill and Chen-Northern, 1990.

The town of Butte is named for Big Butte, a volcanic vent complex that emitted the rhyolite (a fine-grained equivalent of granite) that drapes the northwestern part of the upper Silver Bow basin (Meinzer, 1914). Younger rhyolitic and quartz-porphyry plugs and dikes intrude the quartz monzonite and are often associated with ore deposits. The quartz monzonite and the Boulder Batholith in general were formed over a 10-million year period (78 to 68 million years ago) during late Cretaceous time (Smedes, 1973). Weed (1912) has mapped the exposed bedrock in the Butte region. A generalized geologic map of the igneous rocks in the Butte area is presented in Figure 1-6. The upper 200 to 300 feet of the bedrock aquifer is highly fractured and oxidized; the remainder of the bedrock aquifer is competent bedrock with abundant sulfides (Botz and Knudson, 1970). The composition of the ore body is discussed in Section 2.2.1.5.

Alluvium. More recent unconsolidated Quaternary and semi-consolidated Tertiary valley fill and alluvial deposits line the Silver Bow Creek area (Figure 1-7A and B). These deposits overlie and are derived in part from weathering of the quartz monzonite bedrock and range from over 300 feet thick near the MR Concentrator to less than 30 feet in the Colorado Tailings area. A structurally-controlled, north-south trending bedrock trough east of the Berkeley Pit contains several hundred feet of alluvial deposits (Figure 1-8). The steep drop-off of the bedrock surface by Montana Street (Fig. 1-7B, A-A') may be due to the presence of a normal fault, which brings quartz monzonite bedrock to within 50 feet of the ground surface (Multitech, 1987; Botz, 1969).

1.1.3 Hydrogeology of the Study Area

Two water-bearing rock or sediment units (aquifers) are located in the study area: the alluvial aquifer and the bedrock aquifer.

Bedrock Aquifer. Groundwater in the bedrock aquifer occurs predominantly within fractures, joints and faults in the quartz monzonite and in the underground mine workings (Canonie, 1992a). A weathered and leached zone is present in the upper 100 to 200 feet of bedrock (Botz and Knudson, 1970). The Butte Hill area is composed of bedrock with variable but lesser amounts of alluvial cover than the bedrock in the study area away from Butte Hill. Before dewatering, depth to groundwater ranged from 20 to 100 feet in the vicinity of the Berkeley Pit, and the groundwater flow direction was from north to south (Hydrometrics, 1982). The water level in the mine area was lowered by approximately 4,200 feet by pumping (U.S. EPA, 1994). Currently, a large cone of depression exists around the Berkeley Pit, and depth to groundwater in bedrock is up to 800 to 900 feet below the ground surface (Kelley Mine shaft and Granite Mountain mine).

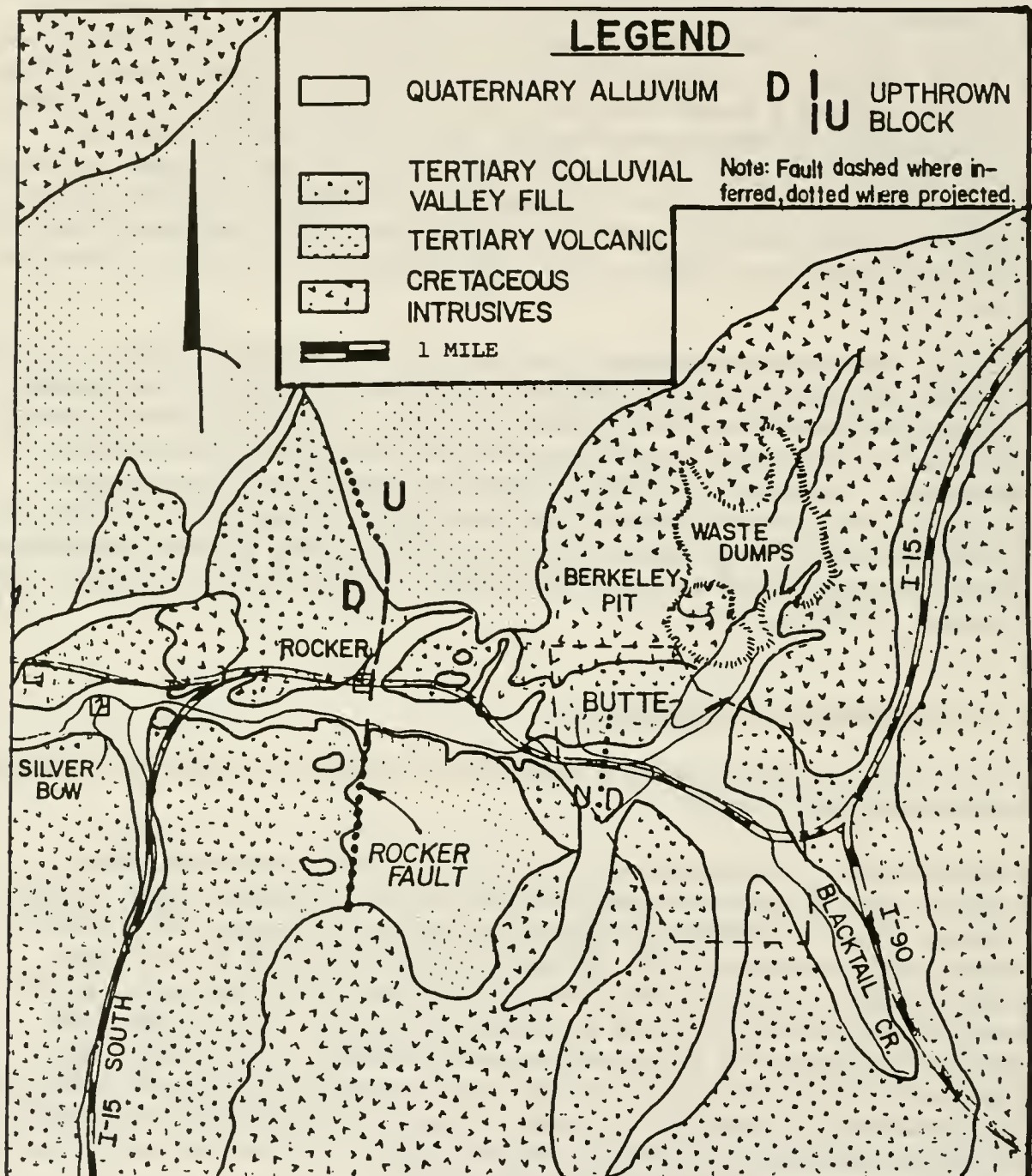


Figure 1-6. Generalized Geologic Map of Butte Area, Montana.
 Source: MultiTech, 1987.

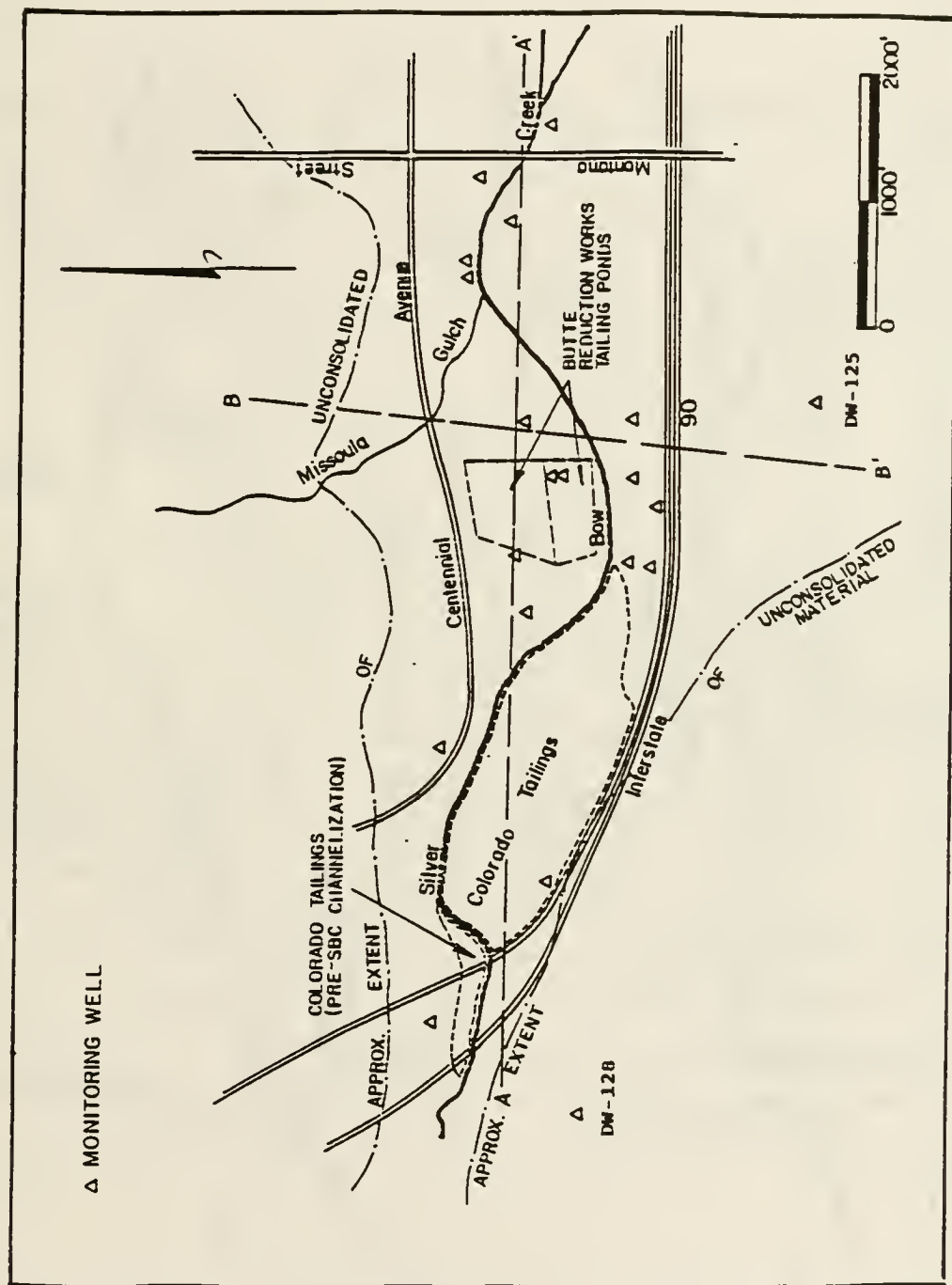


Figure 1-7A. Limits of Unconsolidated Material in Lower Area I. Source: MultiTech, 1987.

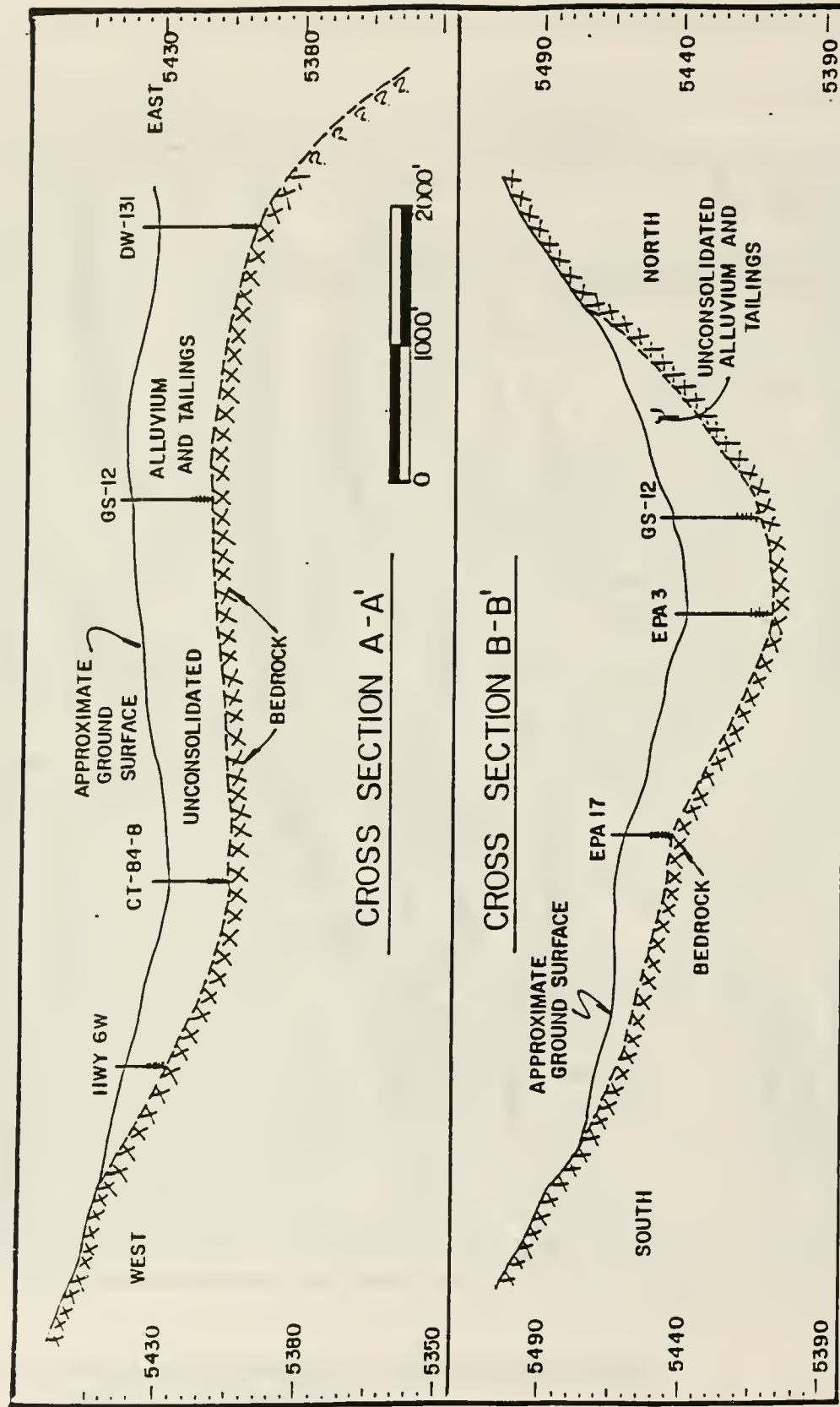


Figure 1-7B. Generalized Cross Sections Showing Depth to Bedrock in Lower Area I. Source: MultiTech, 1987.

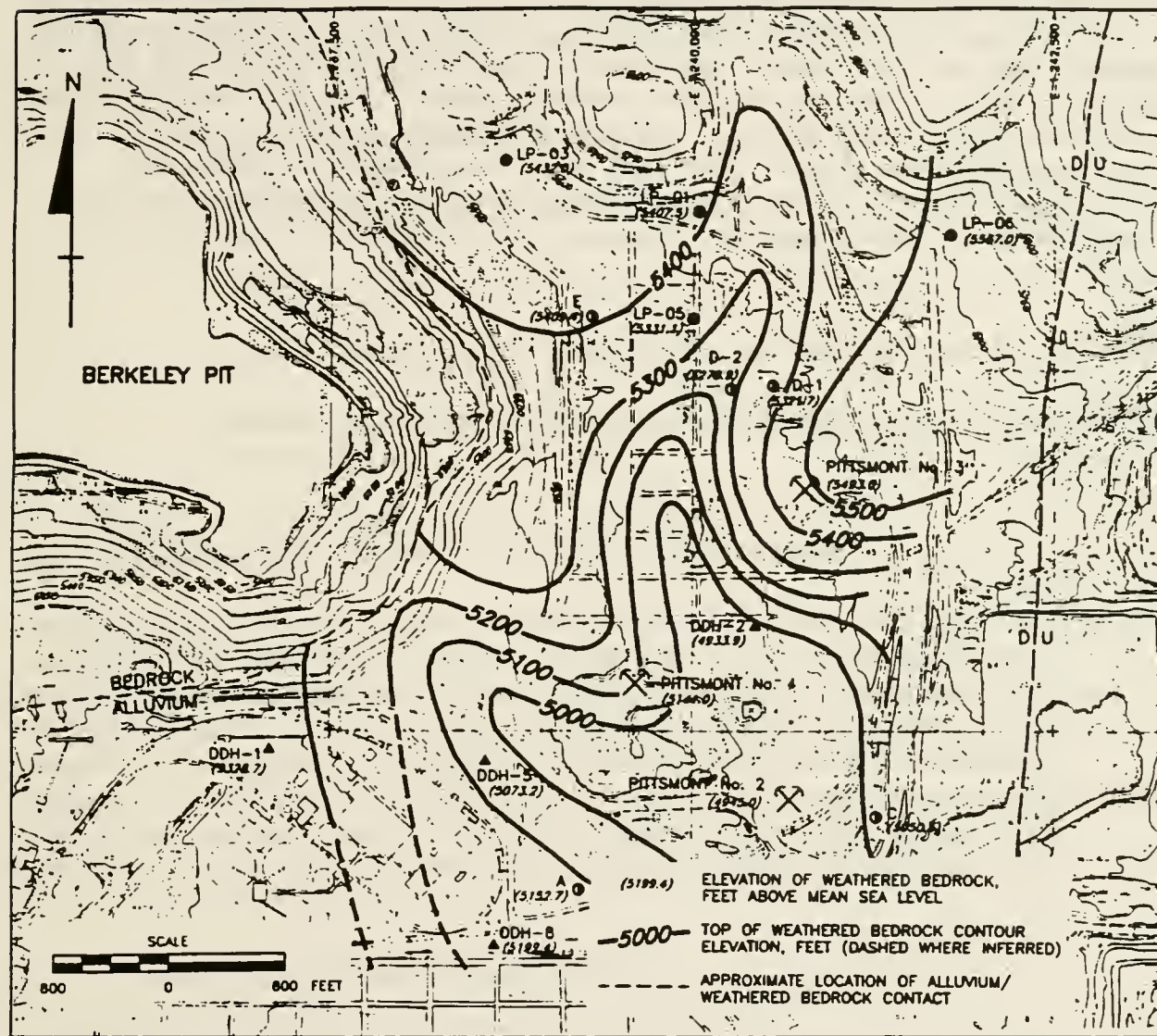


Figure 1-8. Contour Map of the Top of Weathered Bedrock in the Butte Hill Area.
Source: Canonie, 1992a.

Alluvial Aquifer. The alluvial aquifer comprises unconsolidated and semi-consolidated Quaternary and Tertiary valley fill deposits that overlie weathered bedrock in the Silver Bow Creek/Metro Storm Drain/MR Concentrator area and the area to the southeast and east of the Berkeley Pit in the vicinity of the leach pads (see Figures 1-6, 1-7, and 1-8). Groundwater is recharged from precipitation, snowmelt runoff, streams and artificial recharge. Groundwater discharges to springs and sections of Silver Bow Creek below Harrison Avenue (although the majority of groundwater discharge to the MSD is in its lower reaches), the lower reaches of Blacktail Creek, and Silver Bow Creek below the Colorado Tailings. Groundwater flow direction in the Area I OU alluvial aquifer generally is parallel to the MSD/Silver Bow Creek or into the streams in discharge areas. The cone of depression around the Berkeley Pit moves groundwater toward the pit in the Upper MSD area. Groundwater flow patterns in the alluvial aquifer in the Butte Mine Flooding OU are also toward the Berkeley Pit for those portions within the cone of depression. Groundwater flow further east of the pit is to the south.

2.0 GROUNDWATER INJURY DETERMINATION

Groundwater resources are defined as being injured by the release of a hazardous substance if one or more relevant standard is exceeded in groundwater that was potable before the release, and/or if concentrations of substances in groundwater have caused injury to surface water, air, geologic or biologic resources when exposed to groundwater [43 CFR § 11.62(c)]. Exposure pathways from the sources of hazardous substances to the injured resource must be determined [43 CFR § 11.61(a)]. This section describes:

- ▶ Sources releasing hazardous substances
- ▶ Identity of hazardous substances released
- ▶ Duration of release
- ▶ Relevant standards that are exceeded in groundwater resources in the study area
- ▶ Pathways for transport of hazardous substances from the sources to the injured groundwater.

2.1 SOURCES RELEASING HAZARDOUS SUBSTANCES

Both primary and secondary sources can release hazardous substances to groundwater in the study area. Primary sources are directly derived from mining, processing and disposal practices and include: underground mine workings; waste rock or overburden; stock piles; tailings, and waste rock piles. Secondary sources are the result of reworking of primary sources of contamination by physical (i.e., transport in surface water) or chemical (i.e., leaching) mechanisms. Secondary sources of contamination include: streamside tailings; soils and aquifer materials contaminated by primary sources; surface salts; smelter airfall, groundwater contaminated with hazardous substances and acid mine drainage (AMD).

2.1.1 Sources of Groundwater Contamination

A summary of the primary and secondary sources of groundwater contamination can be found in Table 2-1.

Butte Mine Flooding OU. The sources of groundwater contamination in the Butte Mine Flooding OU are: (1) underground mine workings and the walls of the Berkeley and Continental Pits; (2) tailings and waste rock piles; (3) leaking solutions from the leach pads area; (4) leaking solutions from the Yankee Doodle Tailings Pond; (5) contaminated soils and alluvium; (6) leaking solutions from the Weed/MR Concentrator area; and (7) sulfuric acid

Table 2-1
Sources of Groundwater Contamination and
Identity of Hazardous Substances

Contaminant Source	Hazardous Substances Identified
Underground mine workings and pit walls; acid mine drainage ¹	Ag, As, Cd, Cu, Ni, Pb, Sb, V, Zn, sulfides
Waste rock piles near Berkeley Pit ²	Ag, As, Cr, Cu, Pb, Se, V, Zn, sulfides
Buried Parrot and other tailings ²	Ag, As, Cd, Cu, Hg, Pb, Sb, V, Zn, sulfides
Colorado tailings ²	Ag, As, Cd, Cr, Hg, Ni, Pb, Sb, Se, V, Zn, sulfides
Butte Reduction Works tailings ²	Ag, As, Cd, Cr, Cu, Ni, Pb, Sb, V, Zn, sulfides
Manganese stock piles and flue dust ²	Ag, As, Be, Cd, Cr, Cu, Hg, Pb, Ni, Sb, Se, Tl, V, Zn
Slag, slag sand and gravel ²	Ag, As, Be, Cd, Cu, Pb, Ni, Sb, V, Zn
Railroad bed fill ²	Ag, As, Cr, Cu, Pb, Ni, Sb, Se, V, Zn, sulfides
Efflorescent salts ³	Cd, Cu, Pb, Zn
Streamside tailings ³	Cd, Cu, Pb, Zn, sulfides
Contaminated soils ²	Ag, As, Be, Cd, Cr, Cu, Ni, Pb, Sb, Se, V, Zn
Mixed alluvial soils and tailings ²	Ag, As, Be, Cd, Cr, Cu, Hg, Ni, Pb, Se, Tl, V, Zn
Leach pad solutions ⁴	As, Cd, Cr, Cu, Ni, Zn, sulfuric acid
Weed concentrator ⁵ solutions	Cd, Cu, Zn
Sulfuric acid used in underground leaching ⁶	Sulfuric acid

Sources:

¹ Appendices I and IIA. Results from composition of mine water and Berkeley Pit water were used to determine identity of hazardous substances.

² CH₂M Hill/Chen-Northern, 1990, Appendix C-6 and Chapter 4.

³ MultiTech, 1987, Chapter 3 and Appendix B, Part 4, Attach. VI.

⁴ Canonie, 1992a. Table 3.2.2. MCL/SMCL exceedences for hazardous substances in pregnant and leaching solution are used.

⁵ Results from well AMC-5 were used to determine identity of contaminants released from Weed Concentrator operations (MultiTech, 1987, Appendix B, Part 4, Attachment VI).

⁶ Spindler, 1977; Spindler, 1992.

Key: Sb = antimony, As = arsenic, Be = beryllium, Cd = cadmium, Cr = chromium, Cu = copper, Ni = nickel, Pb = lead, Hg = mercury, Se = selenium, Ag = silver, Tl = thallium, V = vanadium, Zn = zinc.

added to the underground mines for copper leaching. The locations of these sources can be found in Figures 1-1, 1-2, and 1-3.

Area I OU. There are three generalized source areas for copper, zinc, cadmium, lead, iron and sulfate in Area I: near the historic Parrott Smelter and buried Parrott tailings (City-County Shop Complex); the Butte Reduction Works tailings impoundment area (north of Silver Bow Creek and west of Missoula Gulch), and the Colorado Tailings area (see Figure 1-5 for locations of these areas). Additional source areas for arsenic include the historic Colorado Smelter and the Silver Bow Creek alluvium west of the Colorado Tailings (CH₂M Hill and Chen-Northern, 1990).

The specific sources of groundwater contamination in the Area I OU are: (1) the buried Parrott tailings; (2) slag, mill and other wastes around the historic Parrott Smelter and the City-County Shop Complex; (3) manganese stockpiles and manganese flue dust in the manganese stock pile/Butte Reduction Works area (removed in 1992); (4) surficial and buried tailings disposed of along the MSD and Silver Bow Creek; (5) the Butte Reduction Works tailings impoundments (partially removed in 1994); (6) the historic Colorado Smelter; (7) railroad ballast; (8) efflorescent salts on tailings piles and along the banks of Silver Bow Creek; (9) streamside tailings along Silver Bow Creek and the Metro Storm Drain; (10) contaminated soils; (11) mixed contaminated soils/alluvial material and tailings throughout Area I; (12) the Colorado Tailings; and (13) mine water and process water discharged to SBC/MSD. The locations of these sources can be found in Figures 1-5 and 2-1.

This report does not address contaminated groundwater associated with the Clark Tailings, which are located about 1 mile south of Area I. Adequate data on the extent of injury associated with the Clark Tailings are not yet available.

2.1.2 Identity of Hazardous Substances

2.1.2.1 Hazardous Substances Derived Directly from Sources

The hazardous substances identified in sources are listed in Table 2-1. All the major metals and metalloids that are listed as hazardous under CERCLA were found in sources of groundwater contamination in the study area [40 CFR § 302.4]. The hazardous substances identified in source materials were: antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, sulfuric acid, thallium, vanadium, zinc and sulfides of several of these hazardous substances (copper, arsenic, zinc, lead, silver, antimony) (see Section 2.2.1.5). Not all sources and alluvial and bedrock groundwaters were analyzed for every hazardous substance identified in the study area.

Groundwater quality data from the Phase II RI are available for the hazardous substances antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, vanadium and zinc (CH₂M Hill and Chen-Northern, 1990). The Phase I RI (MultiTech, 1987), however, only has groundwater quality data for the hazardous substances arsenic, cadmium, copper, lead and zinc. Soils, tailings and waste material samples in the Phase II RI (CH₂M Hill and Chen-Northern, 1990, Volume 1, Chapter 4-1 and Volume II, Appendix C-6) were analyzed for the hazardous substances antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium and zinc. The manganese ore was not analyzed in this study, although it is identified as a material unit (Unit 6B (Manganese Ore Piles), in Table 4-5 in CH₂M Hill and Chen-Northern, 1990). The hazardous substances identified in the manganese flue dust are likely to be similar to (and a subset of) those in the manganese ore piles because the flue dust is derived from smelting of the ores. The Phase I RI (MultiTech, 1987) only analyzed soils, tailings and waste materials for copper, cadmium, lead, zinc and sulfides. Prior to the installation of the wastewater treatment system (1972), sulfuric acid was added to minewater in the underground mines to increase dissolved copper, which was later extracted in the leach dumps. The underground leaching was discontinued to lower the lime demand for neutralization of underground minewater (Spindler, 1977).

2.1.2.2 Other Substances Resulting from Release and Oxidation of Hazardous Substances

In addition to the hazardous substances identified above, some substances identified in groundwater are not defined as hazardous under CERCLA, yet are derived from mining operations in the study area and are present in concentrations exceeding relevant standards [43 CFR § 11.62(c)(1)(i)]. For groundwater determined to be injured that contains no hazardous substances, it must be demonstrated that the substances causing the injury occur in the groundwater resource as a result of physical, biological or chemical reactions resulting from or initiated by the release of hazardous substances [43 CFR § 11.62(c)(4)]. Acid mine drainage contains very high concentrations of sulfate, iron and other metals. These substances are present in groundwater as a result of the oxidation and dissolution of pyrite and other metal/metalloid sulfides in underground mine workings, tailings and waste rock piles. The acid mine drainage formed by oxidation and dissolution of pyrite further dissolves other metal sulfides and aluminosilicates, which release heavy metals and metalloids, sulfate, iron, manganese and aluminum to groundwater and surface water. A discussion of the formation of acid mine drainage is presented below.

Generation of Acid Mine Drainage

The formation of acid mine drainage (AMD) involves many types of biogeochemical reactions, including: oxidation (both biological and chemical), dissolution, precipitation, hydrolysis and complexation.

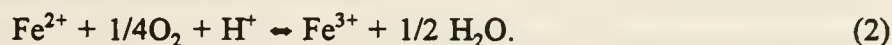


Figure 2-1. Extent of Surface Tailings and Mill Waste Deposits from an August, 1955 Aerial Photograph.
Source: CH₂M Hill and Chen-Northern, 1990.

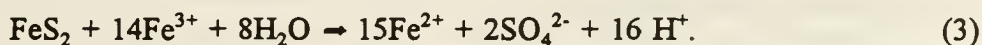
The first step in the formation of AMD is the oxidation and dissolution of pyrite or marcasite (both are iron disulfide minerals) to form acid (H^+), sulfate (SO_4^{2-}) and reduced iron (Fe^{2+}):



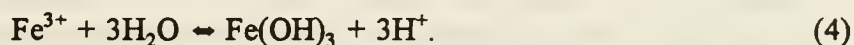
The oxidation of reduced iron is the rate-limiting step in the formation of acid mine drainage. The oxidation rate is accelerated by up to one million times by the presence of the iron-oxidizing bacterium, *Thiobacillus ferrooxidans*:



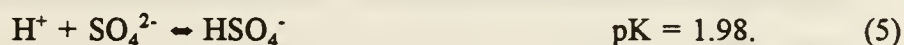
The oxidized iron (ferric iron or Fe^{3+}) produced is also a strong oxidizing agent and will promote further oxidation and dissolution of pyrite (FeS_2):



Ferric iron hydrolyzes above pH 2.2 and eventually precipitates ferric hydroxides or basic iron sulfates. At higher sulfate concentrations, aqueous ferric sulfate complexes [$Fe(SO_4)_2^-$ or $FeSO_4^+$] form, which can inhibit further iron precipitation. Heavy metals such as lead, cadmium, copper and zinc can be removed from solution either by coprecipitation with or adsorption onto ferric hydroxides:

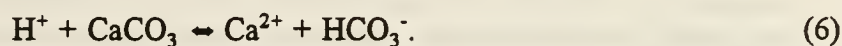


Below about pH 2, the hydrogen ions in acid mine drainage combine with free sulfate ions to form the bisulfate ion (HSO_4^-), which buffers further decreases in pH:



References: (Doyle and Mirza, 1990; Nordstrom, 1982; Olson, 1986; Stumm and Morgan, 1981; University of California, 1988)

These reactions can be slowed, or the acid (shown as H^+ here) that is generated can be neutralized, by the presence of carbonate material:

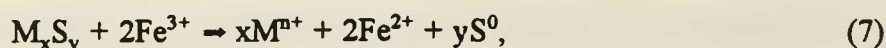


Leaching of Other Heavy-Metal Sulfides

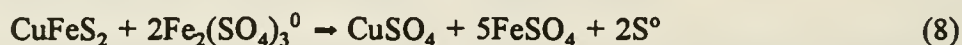
The acid produced by AMD can dissolve other metal sulfide minerals and release sulfate and heavy metals and metalloids such as copper, cadmium, lead, arsenic and zinc to the environment. Chalcocite, enargite, pyrite, covellite, bornite, sphalerite, chalcopyrite, rhodochrosite, tetrahedrite, tennantite, and molybdenite in source materials can be leached by

AMD, and sulfate, copper, zinc, arsenic, silver, iron, manganese, antimony and lead will be released (see Section 2.2.1.5 for composition of these minerals). These minerals, and aluminosilicates in soils and overburden or waste materials, will be leached by the acid and ferric iron in AMD. High concentrations of aluminum can result from leaching of aluminosilicates. Alunite and jarosite (basic aluminum and iron hydroxy-sulfates) will precipitate as waters with leached constituents mix with higher-pH groundwater or surface water.

Acidic ferric sulfate [$\text{Fe}_2(\text{SO}_4)_3^0$] produced by the biologically-catalyzed oxidation of pyrite can act as a powerful oxidant for dissolving other sulfides that contain heavy metals:



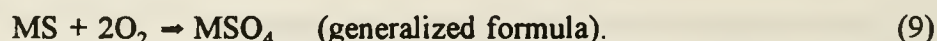
or, for example for chalcopyrite:



where M = metals in other sulfides, such as zinc (Zn), lead (Pb), copper (Cu), iron (Fe), cadmium (Cd), manganese (Mn), nickel (Ni), arsenic (As), cobalt (Co), silver (Ag) and antimony (Sb); S^0 = elemental sulfur. Ferric sulfate is a CERCLA hazardous substance [40 CFR § 302.4].

This indirect leaching mechanism relies upon biological regeneration of ferric iron or ferric sulfate. Ferric sulfate leaching proceeds even in the absence of oxygen or viable bacteria. Elemental sulfur would normally coat the pyrite surfaces and inhibit further reaction, but microbes such as *T. thiooxidans* and *T. ferrooxidans* can oxidize this elemental sulfur film, produce sulfuric acid, and expose pyrite surfaces again and again to further attack by water, oxygen and *T. ferrooxidans* (Hutchins et al., 1986; Olson, 1986).

In addition, bacteria can attack some metal sulfides directly (including pyrite) and produce soluble metal sulfates (Olson, 1986):



Aluminum (Al) can also be leached from soils and sediments by acid mine drainage and is very mobile at low pH values. This can lead to high Al concentrations in affected waters. Aluminum sulfate is a CERCLA hazardous substance [40 CFR § 302.4].

The AMD produced by the reactions described above will leach other sulfides, carbonates and aluminosilicates in source materials in the study area and produce high concentrations of aluminum, sulfate, iron, manganese, and other metals and metalloids. These reactions indicate that, in addition to the substances listed as hazardous under CERCLA, dissolved sulfate, aluminum, manganese and iron can be formed from generation of acid mine drainage

at the Butte site, which is a product of the release of a hazardous substance. Groundwaters downgradient from known source materials (tailings, etc.) are contaminated with sulfate, aluminum, manganese and iron in addition to heavy metals and metalloids. Although sulfate, iron, manganese and aluminum are not specifically listed as hazardous substances under CERCLA, they do result from the release of hazardous substances and cause injury to groundwater. Therefore, iron, sulfate, manganese and aluminum will be considered as if they were listed as hazardous substances.

2.1.3 Duration of Release

Gold was discovered in Silver Bow Creek in 1864, and shallow gold and silver placer mining continued in Silver Bow Creek and its tributaries, especially along Missoula Gulch, until 1876. Underground copper mining also began during this period, and Butte was the most important copper producer in the world between 1887 and 1920. Little mining occurred between 1869 to 1874. Silver mining was regenerated in 1875, and in 1882 large-scale copper mining began. By 1884 there were over 300 mines and eight smelters were operating in the district. Butte was an important mining, milling and smelting district until 1896 when most of the large silver mines closed because of declining silver prices.

In 1884 the Anaconda Smelter was built in Anaconda. Within months of the opening of the smelter in Anaconda, arsenic poisoning occurred in cattle, sheep and horses over a 260-km² area (Moore and Luoma, 1990). Some of the early mills and smelters in the Butte area are identified in Figure 2-2. The major smelters constructed along Silver Bow Creek operated nearly continuously until 1910. By 1910 Anaconda Copper Mining Company had purchased and closed all of the major concentrators/smelter except the Pittsmont, and most of the ore was shipped to the Anaconda smelter for processing. The Pittsmont Smelter operated until 1930. Smelting continued in Anaconda until 1980.

The Parrott Smelter was opened in about 1881 and terminated operations in 1910. Peak annual copper production at the mill was over 14 million pounds. The Butte Reduction Works were constructed in 1883 and operated nearly continuously until 1911 when a fire destroyed the plant. The Colorado Smelter was constructed in about 1878 and operated until about 1904. Peak copper production was in 1902, when over 10 million pounds of copper were produced. Tailings from the facility were deposited onto the Silver Bow Creek floodplain, and Silver Bow Creek eventually required rechannelization to the north because it was encroaching on the tailings area. The Timber Butte Mill operated from 1914 to 1928. In 1917, approximately 150 mines were operating in and around Butte. Tailings from the Timber Butte Mill, Butte and Superior, and East Butte concentrators were sluiced in to tributaries of Silver Bow creek until at least 1918.

By 1950, over 400 underground mines were in operation in Butte, consisting of several thousand miles of interconnected underground mine workings. In the late 1950s/early 1960s,

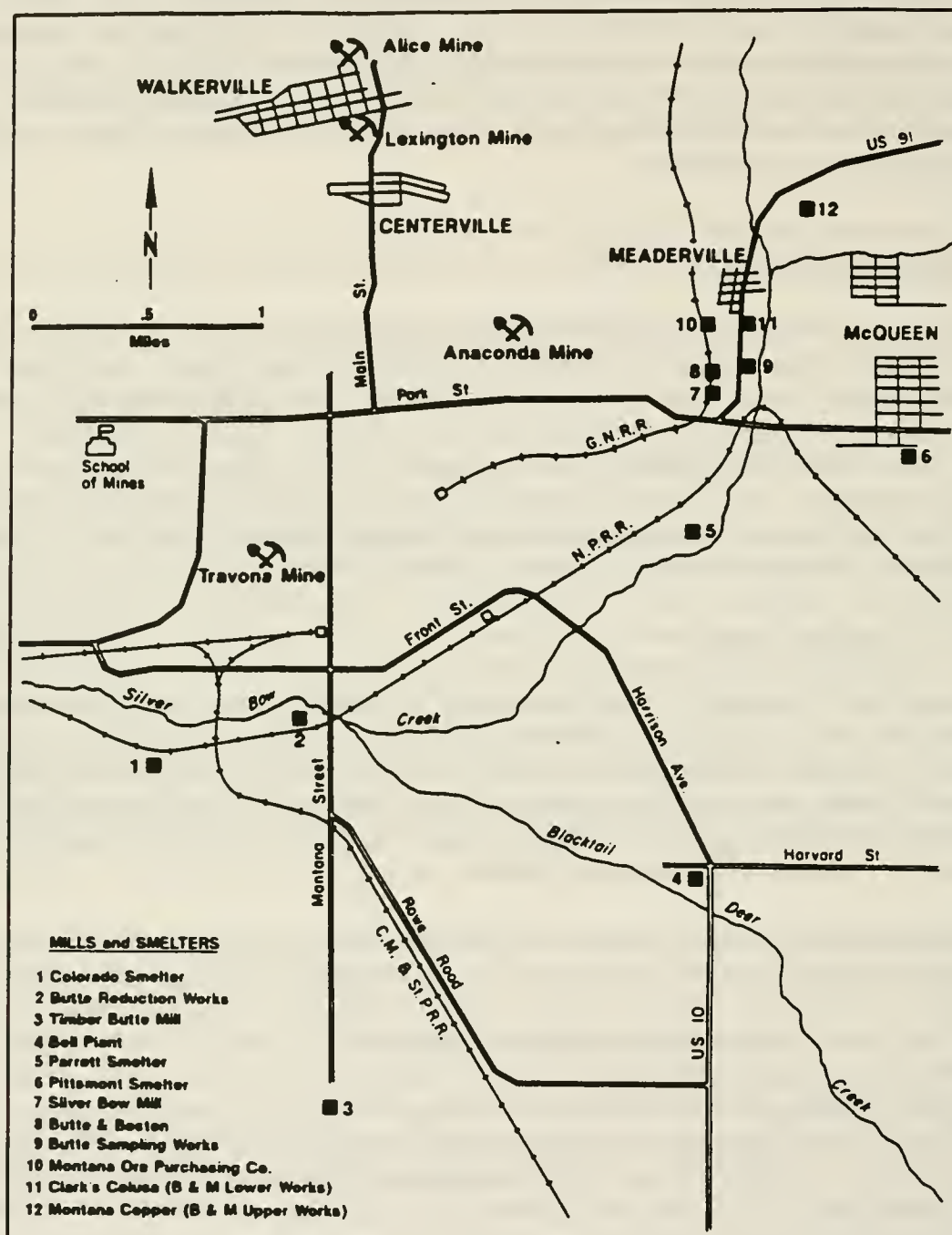


Figure 2-2. Early Reduction Plants in the Butte Area, Montana.

Source: CH₂M Hill and Chen-Northern, 1990.

the mining district in Butte Hill was separated into the East Camp and the West Camp by bulkheads. In 1965, basements along Front Street in Butte began to flood with groundwater from the West Camp area. In order to decrease groundwater discharge to Butte basements, Anaconda Minerals Company (AMC) drilled relief well #21 (directly north of Silver Bow Creek and east of Missoula Gulch), which flowed into Missoula Gulch for three years. Water levels dropped in the spring of 1969 for an unknown reason but began to rise again in May 1984.

The Metro Storm Drain was constructed as a WPA project in the early 1930s. The Domestic Manganese and Development Company facility, which produced manganese ore, operated from 1928 to 1959.

In 1964, the Weed Concentrator (now the MR Concentrator) became operational and discharged untreated waste to upper Silver Bow Creek (Metro Storm Drain) until 1972. The upper MSD historically received process wastewater inflow averaging approximately 13 cfs from the Weed Concentrator. Primary treatment began at the Weed Concentrator in 1972. A secondary system was installed at the Weed Concentrator in 1975. AMC operated the Weed Concentrator until early 1983. MRI purchased the Concentrator and began operations again in 1986.

The Berkeley Pit, owned by the Anaconda Copper Mining Company, began operating in July 1955. Ore from the Berkeley Pit was smelted in Anaconda. In 1977 ARCO purchased the Anaconda Copper Mining Company and changed the company name to Anaconda Minerals Company (AMC). AMC operated the Butte Mine until 1983. Mining in the Berkeley Pit ceased in 1982. The large waste dumps were receiving material from the Berkeley pit until its closure in 1982. The last underground mine, the Kelley, closed in 1981. The underground workings and the pit were continuously dewatered at a rate of 4,000 to 5,000 gpm through pumping of underground workings, and the water was discharged to the Metro Storm Drain/Silver Bow Creek. Pumping stopped in April 1982, and the Pit closed in June. ARCO closed the adjacent East Berkeley Pit in 1983.

Montana Resources Inc. (MRI) purchased the operations, including the Berkeley Pit, East Berkeley Pit, Continental East Pit, and the Yankee Doodle Tailings Ponds in 1985 and resumed mining in the East Berkeley Pit (now the Continental Pit) in July 1986. In 1989 American Smelting and Refining Company (ASARCO) purchased minority ownership of MRI's Butte operations. MRI and ASARCO are currently mining ore from the East Berkeley Pit and producing copper and molybdenum concentrates at the MR Concentrator. Leachate from the leach pad area (low-grade ore previously mined from the Berkeley Pit) is currently being processed at the Precipitation Plant. The precipitation plant and leach pads were constructed in the early 1960s.

All sources remaining in the study area continue to release hazardous substances to the present day.

Sources for Section 2.1.3: (Canonie, 1992a; CH₂M Hill and Chen-Northern, 1990; MultiTech, 1987; Smith, 1953; Montgomery, 1993).

2.1.4 Relevant Standards

An injury to groundwater from release of a hazardous substance is defined as an exceedence of one or more of the following physical or chemical quality aspects of the groundwater resource [43 CFR § 11.62(c)]:

- (1) Concentrations in excess of drinking water standards established under the Safe Drinking Water Act (SDWA), or other Federal or State laws that establish such standards, in groundwater that was potable before release of the hazardous substance. These drinking water standards include maximum contaminant levels (MCL), maximum contaminant level goals (MCLG), and secondary maximum contaminant levels (SMCL).
- (2) Concentrations of substances sufficient to have caused injury to surface water, air, geologic or biologic resources when exposed to groundwater.

The relevant standards for groundwater injury in the study area are determined to be the primary drinking water standards (MCLs, MCLGs) and the secondary drinking water standards (SMCLs) established under the Safe Drinking Water Act and Montana State Law. These standards are listed in Table 2-2.

In addition, concentrations of hazardous substances in groundwater have caused injury to surface water in areas where the Metro Storm Drain and Silver Bow Creek are gaining streams. Concentrations of hazardous substances in groundwater have also caused injury to geologic resources (soils, aquifer materials) as a result of fluctuations in the groundwater table. Changes in the elevation of the groundwater table can occur either seasonally or as a result of changes in artificial recharge (e.g., operation and then draining of process ponds at the historic Weed Concentrator) or pumping and mine flooding associated with the Berkeley Pit. This type of injury is discussed in the Pathway Determination Section (2.2).

2.1.5 Acceptance Criteria

Injury to groundwater resources is determined by measurement of concentrations of a hazardous substance or a constituent caused by release of a hazardous substance (e.g., sulfate) in two groundwater samples from the same geohydrologic unit. The samples must be taken from either two properly constructed wells, a well and a spring or seep, or two springs or seeps that are separated by a straight-line distance of at least 100 feet [43 CFR § 11.62(c)(2)]. Groundwater samples in the Butte Hill bedrock aquifer are taken from wells or shafts that are

Table 2-2
Primary and Secondary Drinking Water Standards
 (µg/l except where noted)

Contaminant	MCL	Montana Water Quality Standards	MCLG	SMCL
Aluminum	--	--	--	50-200
Antimony	6	14	6	--
Arsenic ¹	50	0.018	50	--
Barium	2,000/1,000 ⁵	1,000	2,000	--
Beryllium	4	4	4	--
Cadmium	5	5	5	--
Chromium	100	100	100	--
Copper ²	TT ³	1,000	1,300	1,000
Fluoride	4,000	4,000	4,000	2,000
Iron	--	300	--	300
Lead ²	TT ⁴	15	0	--
Manganese	--	50	--	50
Mercury	2	0.14	2	--
Nickel	100	100	100	--
pH	--	--	--	6.5-8.5
Selenium	50	50	50	--
Silver	--	--	--	100
Sulfate (mg/l)	500 ⁵	--	--	250
Thallium	2	1.7	0.5	--
Zinc	--	5,000	--	5,000

¹ Under revision; proposed rule due November 1995.

² Treatment technique requirement in effect.

³ Action level = 1,300 µg/l.

⁴ Action level = 15 µg/l (at tap).

⁵ Proposed MCL; proposed rule due December 1994.

Sources: Safe Drinking Water Act [42 USC 300f-300j-10]; State of Montana, 1994.

at least 100 feet apart. Groundwater samples in the alluvial aquifer are taken from wells that vary from less than to much greater than 100 feet apart. Therefore, acceptance criteria have been met for both aquifers.

2.2 PATHWAY DETERMINATION

The pathway determination addresses the route and manner of transport of the hazardous substances from the location of their release to the location of the injured groundwater resource. The pathway determination includes consideration of: (1) the chemical and physical characteristics of the released hazardous substances when transported by natural processes or while present in natural media; (2) the rate or mechanism of transport by natural processes of the released hazardous substance; and (3) combinations of pathways that may transport released hazardous substances to the groundwater resource [43 CFR § 11.63(a)].

2.2.1 Physical and Hydrodynamic Characteristics of the Aquifers and Unsaturated Zone

2.2.1.1 Local Geographical Extent of Aquifer and Confining Units

Two water-bearing rock or sediment units (aquifers) are located in the study area: the alluvial aquifer and the bedrock aquifer. The alluvial aquifer comprises unconsolidated Tertiary and Quaternary valley fill deposits that overlie weathered bedrock in the Silver Bow Creek/Metro Storm Drain/MR Concentrator area and the area to the southeast and east of the Berkeley Pit in the vicinity of the leach pads (see Figures 1-7 and 1-8). As discussed in Section 1.1.2, the bedrock aquifer is predominantly in the weathered and fractured upper 200 to 300 feet of the Butte quartz monzonite. In places, a layer of clay-rich oxidized material (Meinzer, 1914) or volcanic ash (Canonie, 1992a; Botz and Knudson, 1970) above the bedrock may inhibit transport of groundwater between the alluvial and bedrock aquifers.

Groundwater in the bedrock aquifer occurs predominantly in fractures, joints, faults and in the underground mine workings. Productivity of the aquifer in the absence of mine workings is limited by fracture-controlled permeability (Canonie, 1992a).

2.2.1.2 Depth to Saturated Zone Beneath the Site

Bedrock Aquifer. Before dewatering, depth to groundwater ranged from 20 to 100 feet in the vicinity of the Berkeley Pit, and the groundwater flow direction was from north to south (Hydrometrics, 1982). Currently, a large cone of depression exists around the Berkeley Pit, and depth to groundwater in bedrock is up to 770 to 945 feet below the ground surface (in the Kelley and Granite Mountain shafts, respectively, as measured in November 1994). Water

levels in bedrock monitoring wells B, E, and F are 165 to 350 feet higher than in other bedrock wells, as measured in November 1994. These wells are not in an area of extensive mine workings, which have much higher hydraulic conductivities than bedrock fractures. Water levels in the West Camp area are about 290 feet higher than in the East Camp system, as measured in Travona (West Camp) and Anselmo (East Camp) shafts in November 1994, suggesting that there is only a partial hydraulic connection between the Camps. However, some interconnection is inferred because of the concurrent rise in East and West Camp water levels (CDM/FPC, 1990; MDHES, 1992). The West Camp (Travona) is pumped intermittently, and water levels consequently fluctuate occasionally.

The volume of water in the Berkeley Pit increases by approximately 5 million gallons per day (mgd). The volume increase is contributed by surface water flow (1.69 mgd average, most coming from the Horseshoe Bend area); alluvium inflow (0.58 mgd); bedrock aquifer inflow (2.49 mgd); and direct precipitation, adjacent runoff, and evaporation (0.30 mgd) (U.S. EPA, 1994). The rate of rise of the water level elevation in the Berkeley Pit is shown in Figure 2-3. The average rate of rise is about 2.5 ft/month, and this rate has not slowed appreciably since December 1991.

Alluvial aquifer. Depth to groundwater in the unconsolidated valley fill ranges from 2 to over 60 feet, with greater depths to groundwater occurring upgradient near the Berkeley Pit/upper MSD area (CH₂M Hill and Chen-Northern, 1990; Canonie, 1992a). Water levels in the alluvial aquifer fluctuate approximately five to seven feet annually in the vicinity of Lower Area I (LAO — the area from Montana Street to the west end of the Colorado Tailings).

2.2.1.3 Recharge/Discharge Areas and Sources

Groundwater is recharged from precipitation, snowmelt runoff, streams and artificial recharge. Sources of groundwater recharge to the Area I OU include the areas to the east and south of the Berkeley Pit, the Blacktail Creek alluvium, Butte Hill and the foothills south of the Colorado Tailings. The lower portion of LAO receives groundwater from the south (Montana Pole site) and the north (Missoula Gulch area) (CH₂M Hill and Chen-Northern, 1990). Artificial recharge from the leach pad area and the Yankee Doodle Tailings impoundment occurs northeast of the Berkeley Pit. Groundwater mounding has been decreasing in the MR Concentrator area since the on-site process ponds were drained, indicating that leakage during active operations was artificially recharging groundwater in the area (CH₂M Hill and Chen-Northern, 1990).

Artificial recharge to the alluvial and possibly the bedrock aquifer occurs from the over 100-year old Butte municipal water supply, which has been estimated to leak 2.4 million gallons per day (mgd) (Montgomery, 1988). Groundwater discharges to springs and sections of Silver Bow Creek below Montana Street where the bedrock-alluvial interface is closer to the ground surface. The lower reach of the Metro Storm Drain from about Harrison Avenue to

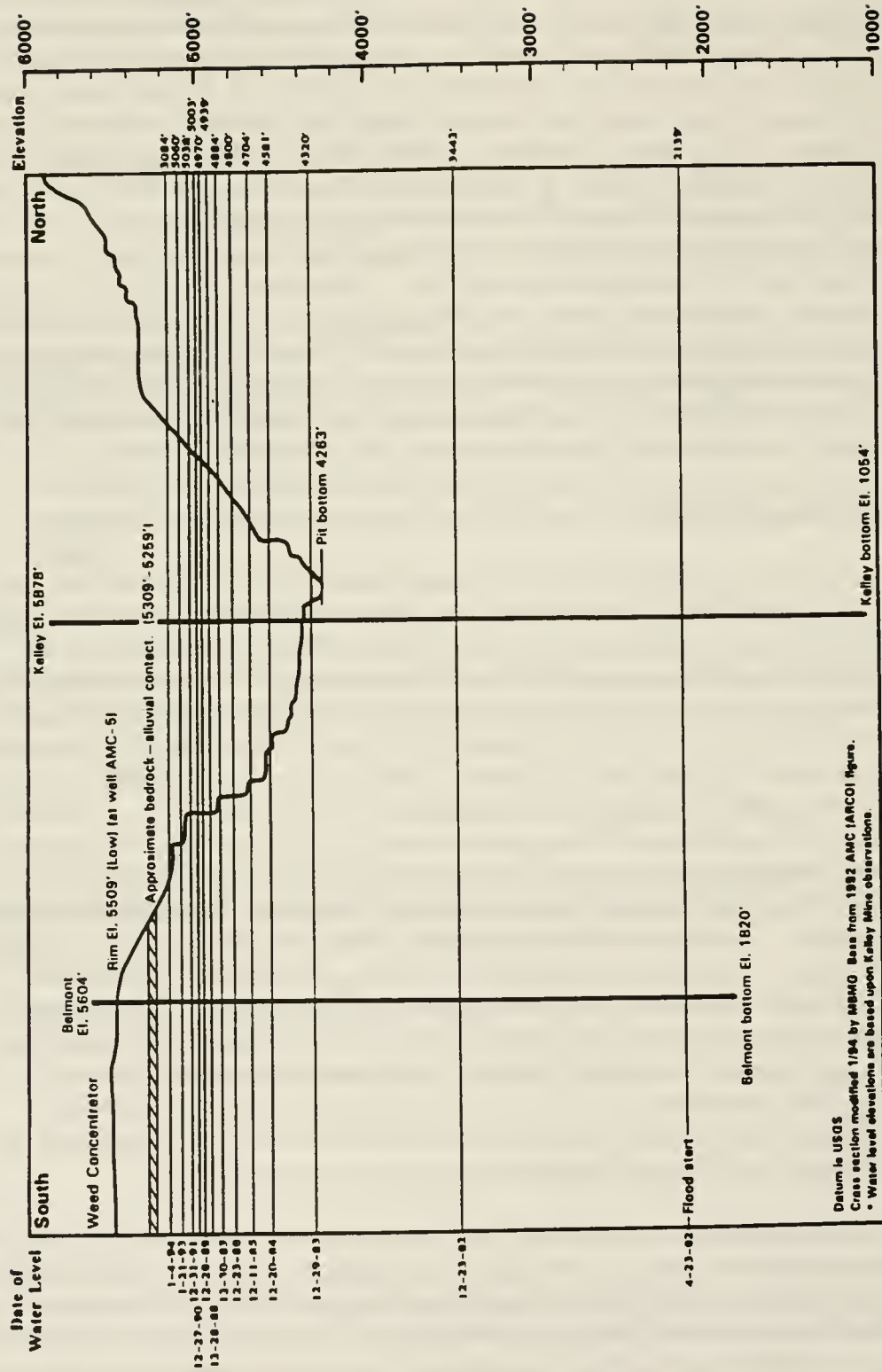


Figure 2-3. Cross-Section of Berkeley Pit with Water Level Elevations Measured in December of Each Year from 1982-1993, as Measured in the Kelley Mine. Source: MBMG, 1994.

Blacktail Creek is also a groundwater discharge area. The lower reaches of Blacktail Creek, and Silver Bow Creek near the Colorado Tailings are gaining streams where groundwater discharges to surface water (MultiTech, 1987).

Local Recharge Rates. The mean annual precipitation for the Butte area is 12.69 inches based on a 96-year period of record (USDA-SCS data for Butte Airport). MSE, Inc. (MSE, 1992) calculated the infiltration rate for 187 acres of mining-disturbed area on the Butte hill. It was reported that 62 percent of the total precipitation or 76 gallons per minute (0.1 mgd) infiltrates to groundwater. Dewatering of the underground workings required a continuous discharge ranging from 5.7 to 7.2 mgd until 1982. The pumping rate fluctuated seasonally, indicating that the bedrock aquifer is recharged by infiltration (CDM/FPC, 1990).

2.2.1.4 Direction of Groundwater Flow in Aquifers

Bedrock aquifer. Not much information is available on groundwater flow patterns in or aquifer characteristics of the bedrock aquifer underlying the alluvial aquifer along Silver Bow Creek. Both aquifers are intersected by the Berkeley Pit. The water level contour map and groundwater flow directions for the bedrock aquifer around the Berkeley Pit are shown in Figure 2-4. A large cone of depression exists around the Berkeley Pit, and groundwater flow direction in the bedrock aquifer is toward the pit in all areas around the pit. Groundwater flow direction in the West Camp (Emma and Travona mines), which was separated from the East Camp by bulkheads in the late 1950s/early 1960s, is not currently toward Silver Bow Creek, but water in the Travona shaft is only 36 feet below the Silver Bow Creek alluvium.

Alluvial aquifer. Groundwater flow patterns in the alluvial aquifer around the Berkeley Pit are influenced by the cone of depression surrounding the Pit. A groundwater divide exists between the Continental pit and the MSD near the MR Concentrator, and groundwater north of the divide generally flows into the Pit, while groundwater south of the divide flows parallel or toward the MSD and Silver Bow Creek (Figures 2-5, 2-6A, and 2-6B. Also see Figure 3-49 in CH₂M Hill and Chen-Northern, 1990 for 1990 depths to groundwater table). A cross-sectional view showing water levels in the bedrock and alluvial aquifers on the east side of the pit near the leach pads area is displayed in Figure 2-7. The location of cross-section A-A' can be found in Figure 2-4. In Area I, groundwater from the Blacktail Creek alluvial system enters the upper Silver Bow Creek system (both groundwater and surface water) at the intersection of the MSD and Silver Bow Creek. The average horizontal hydraulic gradient of the Butte Hill alluvial aquifer, as calculated from a water level contour map, was 0.044; the groundwater velocity was estimated as 1 to 20 ft/d (364 to 7,280 ft/yr) (Botz and Knudson, 1970).

A downward groundwater gradient exists in the area near the City-County shop complex (wells GS-41, GS-42, GS-10, GS-43), while an upward gradient exists southwest of Harrison Avenue (wells GS-35, GS-9, GS-11, GS-31) (CH₂M Hill and Chen-Northern, 1990,

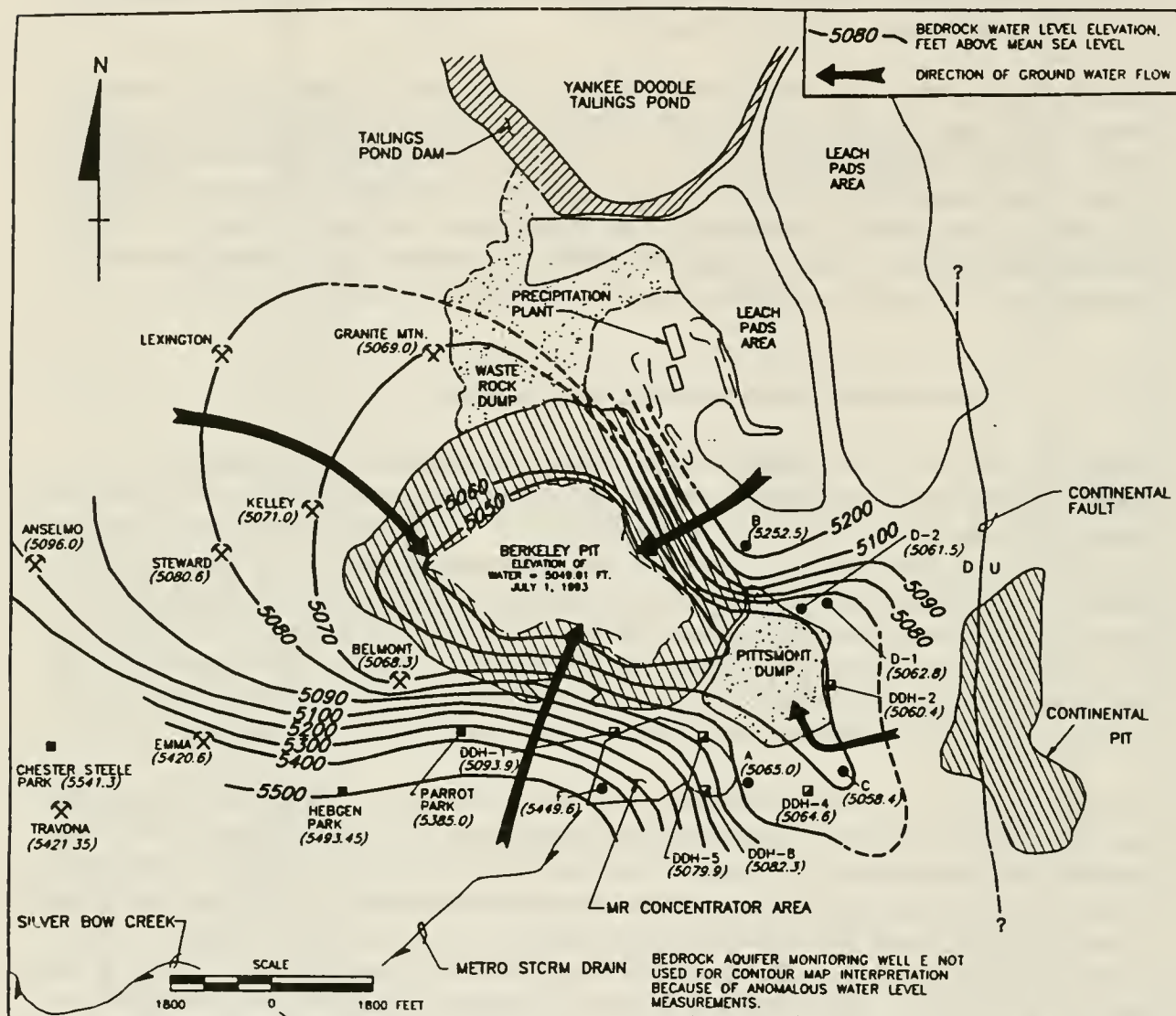


Figure 2-4. Water Level Contour Map and Theoretical Flow Paths for the Bedrock Aquifer in the Butte Hill Area. Source: ARCO, 1994.

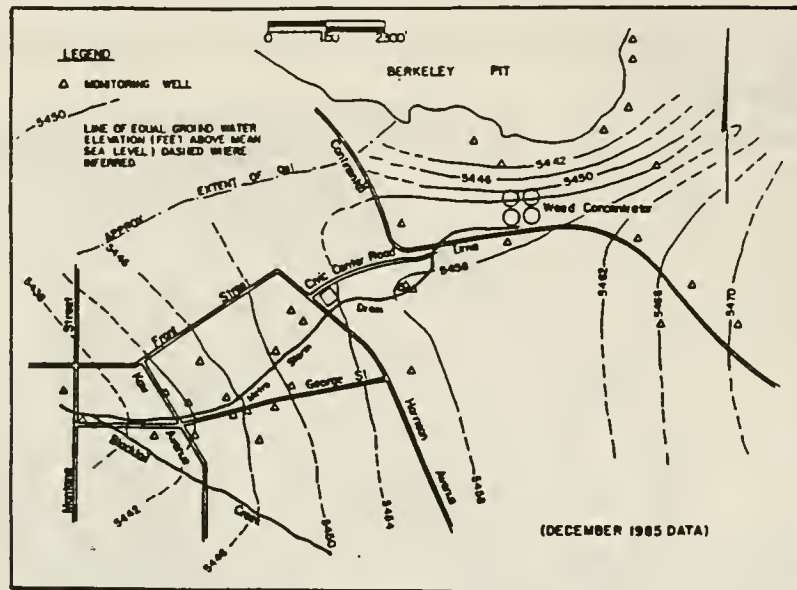


Figure 2-6A. Water Level Contour Map for the Alluvial Aquifer in Area I - Metro Storm Drain Area.

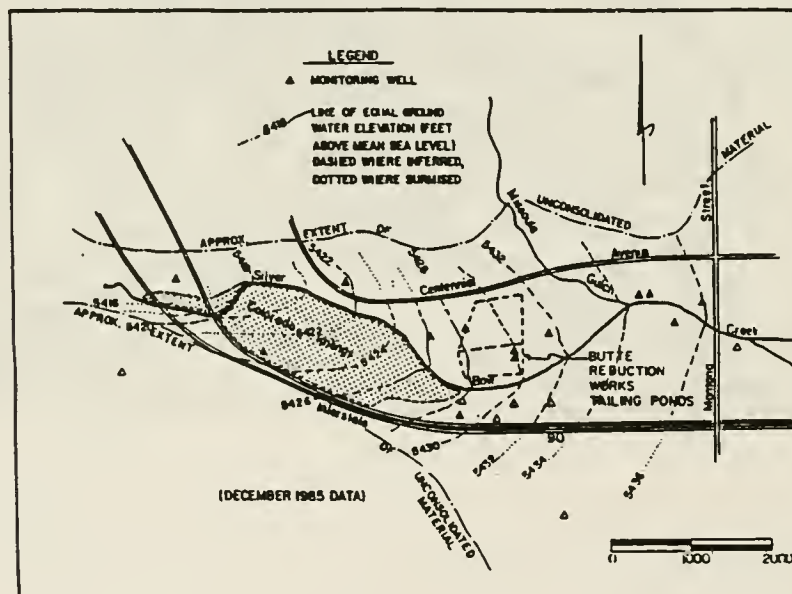


Figure 2-6B. Water Level Contour Map for the Alluvial Aquifer in Area I - Lower Area I.

Source: MultiTech, 1987.

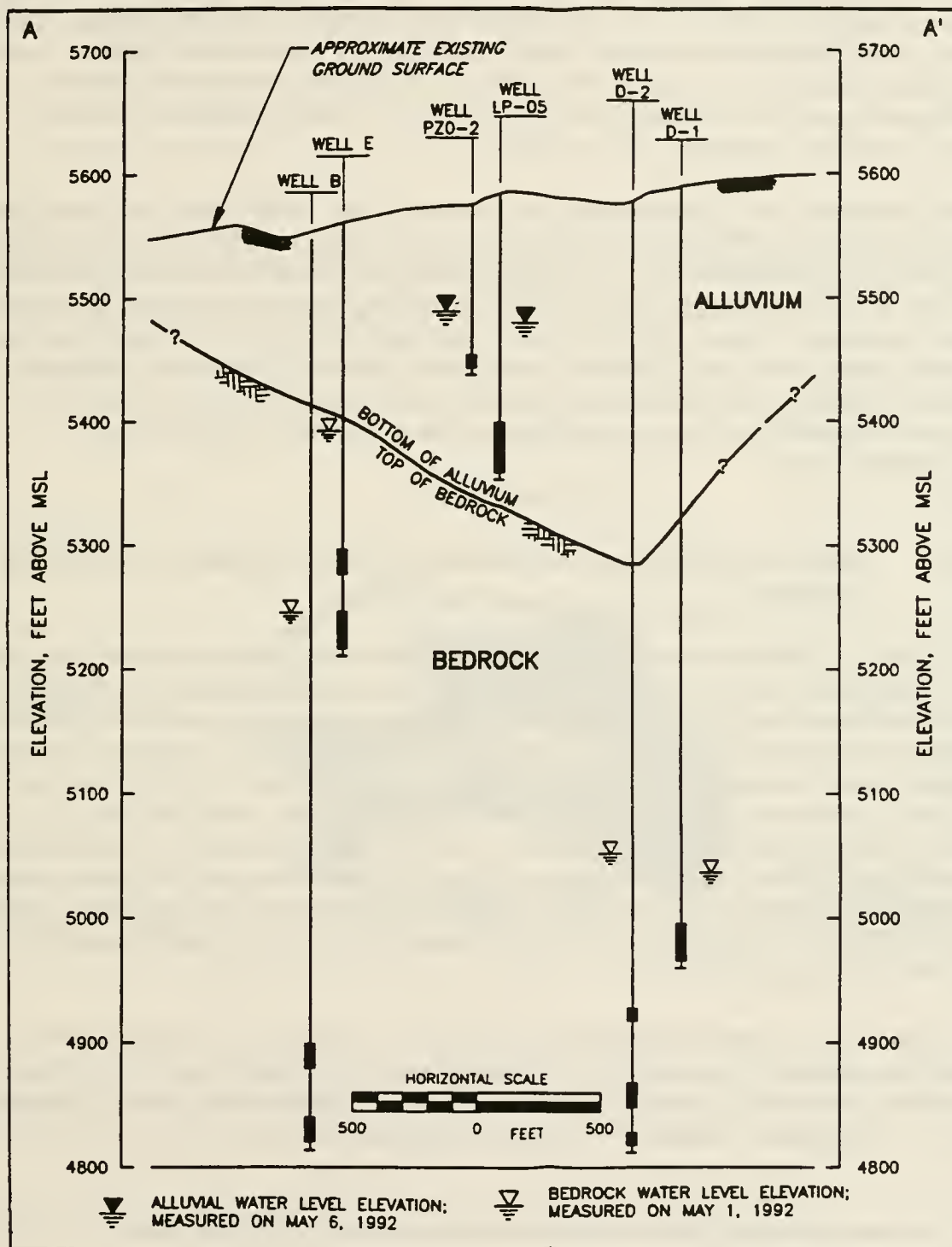


Figure 2-7. Cross-Section of Water Levels in Alluvial and Bedrock Aquifer in Butte Mine Flooding OU. Source: Canonie, 1992a.

Fig. 3-51). The downward gradient may be caused by: a high permeability zone at depth; a dewatered bedrock system below the saturated alluvial groundwater system, leakage from the unlined process ponds at the previous Weed Concentrator, or the downward gradient could simply be the normal pattern in a recharge area. AMC stopped operations at the Weed Concentrator in early 1983; water levels in wells near the Weed Concentrator declined between 5 to 9 feet from early 1983 to 1986.

Montana Resources, Inc. began operating the Concentrator in 1986; water levels in the same wells began to rise in 1986 to mid-1987 and have been stable since that time. These changes in water levels in wells proximal to the Weed Concentrator indicate that leaking of process ponds (the Barrel Ponds) to the alluvial aquifer most likely explains changes in groundwater vertical gradients in this area (CH₂M Hill and Chen-Northern, 1990). The upward gradient in the middle section of the MSD indicates a decrease in permeability in deeper sediments to the southwest or a decrease in the thickness of saturated sediments. There are fine-grained sediments at 80 to 100 feet below the ground surface in this area (CH₂M Hill and Chen-Northern, 1990).

2.2.1.5 Lithology, Mineralogy and Porosity of Rocks or Sediments Comprising the Aquifers

Bedrock Aquifer. Groundwater occurs in the quartz monzonite bedrock throughout the Butte area. Groundwater flow through the bedrock aquifer in the Butte Mining District area occurs in four possible pathways: (1) joints; (2) discrete fractures; (3) the fractured matrix; and (4) underground mine openings. There are two subunits in the bedrock, a weathered zone and a competent zone. The weathered zone consists of clays interspersed with pebble- and cobble-sized rock fragments and is 100 to 200 feet thick. The competent zone underlies the weathered bedrock and consists of unweathered, highly fractured bedrock. The fracture zone in the competent bedrock extends at least as deep as 350 feet below the weathered/competent bedrock contact and provides the primary groundwater flow pathways in the bedrock aquifer (Canonie, 1992a). The underground workings increase the amount of aquifer storage by about 13% (U.S. EPA, 1994).

Fracture porosity is commonly reported to range from < 1 to 10 percent. Metesh (1990) estimated the porosity in the vicinity of the Marget Ann Mine (Outer Camp) as 5 percent. The porosity in the bedrock aquifer has not been measured but is assumed to be 1 percent fracture porosity plus an additional 0.23 percent to account for the mined volume (see Section 3.2.2).

There are three concentric zones of ore/vein deposition in the Butte area (Meyer et al., 1968; Sales, 1913) (Figure 2-8):

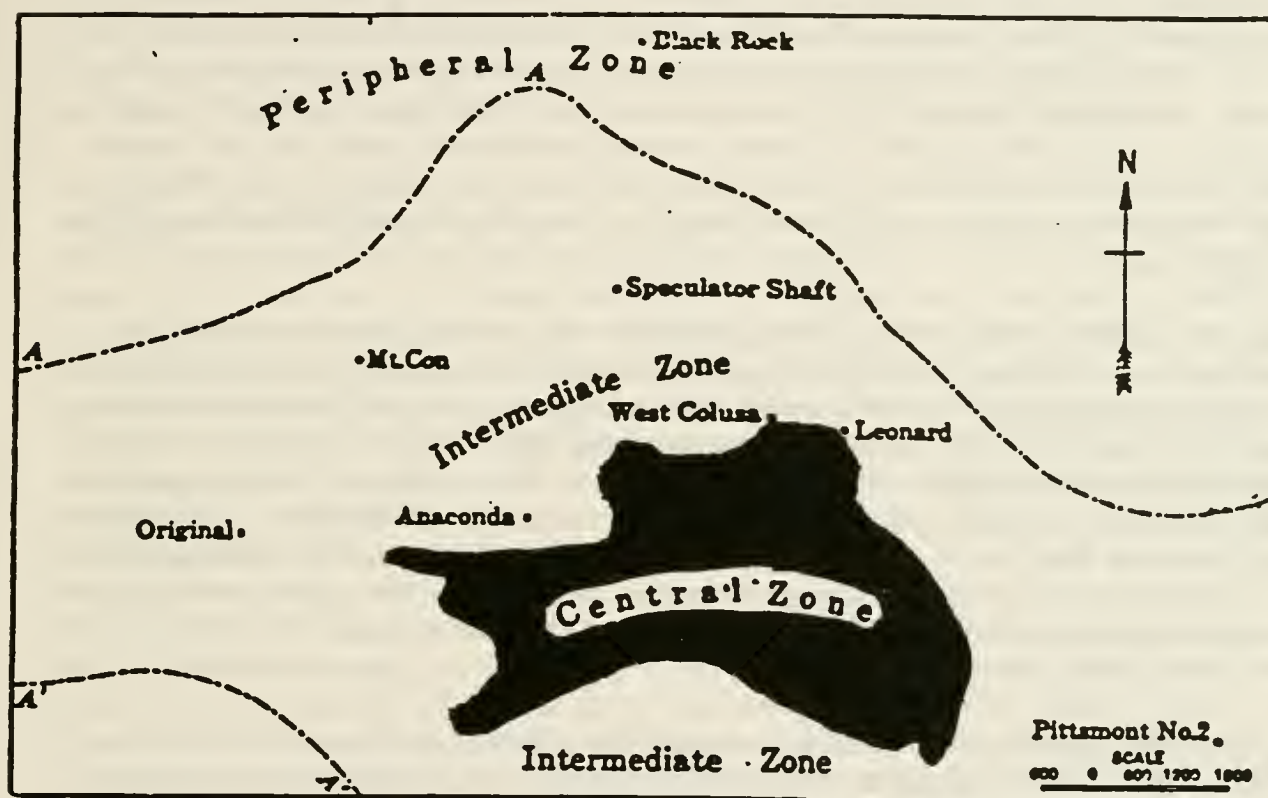


Figure 2-8. Plan Map at Elevation 4,600 Feet Illustrating the General Distribution of Ore Zones in the Butte Area. Source: Sales, 1913.

- ▶ Central Zone (copper)
- ▶ Intermediate Zone (silver, zinc, lead and manganese)
- ▶ Peripheral Zone (silver, gold, zinc).

The most common minerals in the central zone are chalcocite (Cu_2S) and enargite (Cu_3AsS_4), with pyrite and quartz gangue and lesser amounts of bornite (Cu_5FeS_4) and covellite (CuS). The most common minerals in the intermediate zone are chalcocite, enargite, sphalerite (ZnS), rhodochrosite (MnCO_3) and galena (PbS), with lesser amounts of chalcopyrite (CuFeS_2), tetrahedrite ($((\text{Cu}, \text{Fe}, \text{Zn}, \text{Ag})_{12}\text{Sb}_4\text{S}_{13})$) and tennantite ($((\text{Cu}, \text{Fe}, \text{Zn}, \text{Ag})_{12}\text{As}_4\text{S}_{13})$). Molybdenite (MoS_2) is also present. The peripheral zone contains vein fillings of rhodochrosite and rhodonite ($\text{Mn}(\text{SiO}_3)_2$), sphalerite, galena, quartz, and lesser amounts of chalcopyrite and pyrite. The Butte Mining District has also produced lesser quantities of cadmium, bismuth, arsenic, selenium, and tellurium in addition to major production of gold, silver and copper (CH₂M Hill and Chen-Northern, 1990). [Cu = copper; As = arsenic; S = sulfur; Fe = iron; Zn = zinc; Mn = manganese; CO_3 = carbonate; Pb = lead; Ag = silver; Sb = antimony; Mo = molybdenum].

Alluvial Aquifer. The Butte Quartz Monzonite serves as the principal parent material for alluvium and colluvium in the Butte valley. Grain size in the alluvium ranges from clay to gravel and is often poorly sorted. Areal continuous layers of a given lithology are most often restricted to a few hundred feet. Competent clay layers are often encountered in areas associated with the floodplain of Silver Bow Creek and Blacktail Creek. Several wetland areas that have been filled with mine waste are also evident on the floodplain. The sandy clay layers are likely to act as local aquitards or aquicludes. However, numerous excavations for pipelines, plant activities, and the groundwater / product collection system have disturbed the upper portion of the aquifer. Thus, the confining nature of these units is probably restricted to local extent (tens of feet).

Column tests were conducted on alluvial material from the Montana Pole site in LAO (Moore, 1989). The composition of the alluvial material, based on four test sites, was 7 to 11% gravel, 9 to 20% silt and clay, and 71 to 81% sand. The porosity ranged from 28 to 37%, with an average of 32% porosity.

The composition of the alluvial aquifer includes gravel, sand, silt, and clay and is generally not laterally continuous or correlatable. Tailings, waste rock, smelter wastes (slag) and other waste materials overlie the alluvial deposits and are covered locally by man-emplaced fill (CH₂M Hill and Chen-Northern, 1990). Streamside tailings in the upper MSD and Silver Bow Creek area are sandy and have high percentages of pyrite associated with them (MultiTech, 1987). These materials were deposited in a high energy environment where larger-grained (sand-size) and higher-density (density of pyrite = 5.02) particles would tend to settle out.

2.2.1.6 Transmissivity, Hydraulic Conductivity and Hydraulic Connection Between Groundwater and Local Surface Water Resources

Bedrock Aquifer. Hydraulic conductivity values for the bedrock aquifer on the Butte Hill range from 6×10^{-5} cm/s to 3.4×10^{-4} cm/s (62 to 352 ft/yr or 0.17 to 0.96 ft/day) (Metesh, 1990). Canonie (1992a) reported an average value of 5.3×10^{-5} cm/s (54.9 ft/yr or 0.15 ft/day) for wells east of the Berkeley Pit in an area that is not transected by mine workings. Rising-head tests were conducted in seven bedrock wells (A, B, C, D-1, D-2, E, F), and hydraulic conductivities ranged from 7.10×10^{-6} to 3.46×10^{-4} cm/s (0.02 to 0.98 ft/day), with an average of 1.34×10^{-4} cm/s (0.38 ft/day). Three constant discharge aquifer tests were conducted in bedrock wells A, D-2, and E to estimate the transmissivity of the bedrock aquifer. Measured transmissivities ranged from 1.3 to 13.2 ft²/day. (ARCO, 1994).

Alluvial/Bedrock connection. The extent of vertical hydraulic connection between the bedrock aquifer and the alluvial aquifer beneath the site is uncertain. In other areas of the Butte valley, vertical connection between the two aquifers is controlled by the presence of a clay-grus which may act as a low-hydraulic-conductivity, confining layer. The grus is a result of *in situ*, physical weathering of the quartz monzonite resulting in an accumulation of coarse grained fragments. Chemical weathering of the fragments in the presence of groundwater, which tends to form clays, is accelerated by the increased surface area. Fractures and joints are in-filled or collapsed and a clayey, granular zone is formed on top of the bedrock. Post-chemical-weathering transport occurs in some areas and is the source of the clays and silts encountered in the alluvium. In other areas, however, no transport occurs and a hydraulically confining layer is formed.

Based on observations made during drilling at the Montana Pole Treatment Plant site, the MPC transformer storage yard, and LAO, the clay-grus appears continuous and is often greater than 10 feet thick. Exceptions are noted, however, in areas where bedrock water elevation is at or near alluvial groundwater elevation and where bedrock water-levels, although lower than alluvial groundwater levels, are higher than those in the flooded mines. The higher water levels may, in part, be due to vertical recharge from the alluvial aquifer to the bedrock aquifer where the clay-grus is nonexistent or has been eroded.

Alluvial Aquifer. Hydraulic conductivity covaries with lithology throughout the Butte Valley. In the area south of the Montana Resources leach pad area, hydraulic conductivity (K) averaged 2.1×10^{-4} cm/s (217 ft/yr or 0.60 ft/day) with an average transmissivity (T) of 8.55×10^{-1} cm²/s or 79.5 ft²/day, assuming an average thickness of 130 feet (Canonie, 1992a). The highest hydraulic conductivities in the alluvial aquifer are in the intermittent and discontinuous sand and gravel lenses that can be up to 20 feet or greater in thickness (Canonie, 1992a).

Aquifer tests were conducted in four wells within the Area I Operable Unit during the Phase II Remedial Investigation. Hydraulic conductivity (K) ranged from 8.8×10^{-4} cm/s to 5.9×10^{-2} cm/s (911 to 61,060 ft/yr or 8.2 to 17.7 ft/day); aquifer thickness ranged from 19.5 to 35 feet (CH₂M Hill and Chen-Northern, 1990).

Additional aquifer tests have been conducted in the Lower Area I Operable Unit by several entities. ARCO (1991) reported a range of 7.87×10^{-3} cm/s to 1.02×10^{-1} cm/s (8145 to 105,560 ft/yr or 22.3 to 289 ft/day) for hydraulic conductivity (K). Based on an average thickness of 35 feet, transmissivity ranged from 8.39 to 109 cm²/s (780 to 10,133 ft²/day). In the same area, values for hydraulic conductivity in wells at the Montana Pole Treatment Plant site ranged from 3.8×10^{-5} cm/s to 4.2×10^{-2} cm/s (39.3 to 43,466 ft/yr or 0.11 to 119 ft/day) (Keystone, 1992).

Direct measurement of the capillary rise of water in the unsaturated zone has never been conducted on the alluvial material. Moore (1989), however, conducted a capillary column experiment using material from the Montana Pole Treatment Plant site. The capillary rise determined was approximately 1.4 feet. This rise corresponds to that which would be expected for a silty sand and agrees with the lithology of the area.

2.2.2 Primary Pathways for Groundwater Contamination

The predominant pathways for groundwater contamination are: (1) infiltration of precipitation and snow melt through sources of contamination in the unsaturated zone, which leaches hazardous substances to downgradient groundwater; (2) rising of capillary groundwater to sources of contamination in the unsaturated zone, which leaches and transports hazardous substances to downgradient groundwater during an infiltration event; (3) inundation and leaching of source materials in the saturated zone to groundwater via groundwater flow through sources or changes in groundwater level; and (4) transport of contaminated water (i.e., from leaking process solutions or contaminated alluvial groundwater) through the unsaturated or saturated zone to downgradient groundwater, pit water and surface water. The first three pathways involve leaching of source materials, which has been examined in some detail in the study area and nearby areas. The fourth pathway has also been documented around the MR Concentrator and the leach pads area, in the bedrock aquifer below the alluvial aquifer, and in gaining sections of the Metro Storm Drain and Silver Bow Creek.

2.2.2.1 Leaching of Primary and Secondary Source Materials

One of the best methods for assessing the potential for hazardous substances in the unsaturated zone to leach to groundwater is to analyze porewater in the unsaturated zone around the source material. MultiTech (1987) collected and analyzed porewaters from lysimeter clusters in tailings at Ramsay Flats; results are presented in Table 2-3. The first

Table 2-3
Average Concentrations of Contaminants (mg/l) and Average pH in
Porewater at Ramsay Flats

Lysimeter Location	Depth, Ft.	pH	SO ₄	Cu	Zn	Fe	Cd	Pb	As
West	2.0	4.99	6,225	215	1,013	.682	5	.525	.024
	4.8	6.40	--	.168	2.29	7.66	.015	.005	.018
	6.8	6.26	964	.223	11.6	11.1	.023	.224	.038
East	7.5	6.89	1,720	.090	1.29	1.3	.006	.003	.025
	9.5	7.17	1,725	.109	.857	.041	.002	.144	.164

Source: MultiTech, 1987. Appendix B, Part 4, Attachment VI-B.

three lysimeters were in the western cluster, and the last two (7.5 and 9.5 ft) were in the east cluster. Samples were taken at different depths to estimate the tendency for metal flux to groundwater or metal immobilization in the unsaturated zone. The 2-ft deep lysimeter was in tailings material, and the 4.8- and 6.8-ft deep lysimeters were in organic-rich silt and coarse, sandy alluvium, respectively. The two deeper lysimeters in the east cluster were in natural alluvium.

Porewater in the immediate vicinity of the tailings material (West lysimeter, 2.0-foot depth) had extremely elevated concentrations of sulfate, copper, zinc, cadmium and lead, all of which are similar to concentrations found in Area I groundwaters immediately surrounding the three major sources of hazardous substances: the buried Parrott tailings; the Butte Reduction Works area, and the Colorado Tailings. Iron concentrations in porewaters increased with depth, but did not reach the higher end of concentrations in Area I OU. Arsenic concentrations in porewaters were also lower than concentrations in groundwater in Area I OU. The reduced form of both of these elements is more mobile than the oxidized form, and this may affect their mobility and leachability.

Another method for determining the potential of hazardous substances to leach from solids is to perform leach tests on the source materials. Tables 2-4 and 2-5 present the results of water leaches on surface and subsurface materials, respectively, in Area I OU (CH₂M Hill and Chen-Northern, 1990). A water leach is conducted to evaluate the potential of either runoff or infiltrated precipitation to leach contaminants from source materials.

Table 2-4

SUMMARY OF WATER SOLUBLE METALS FOR SURFACE (0 TO 1 INCH) MATERIALS;
AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION

LOCATION/LITHOLOGY INFORMATION				CONCENTRATION (µg/L)					
GEOGRAPHIC AREA	SAMPLE NO.	MATERIAL UNIT	SAMPLED INTERVAL (feet)	As	Cd	Cr	Cu	Pb	Zn
Upper Metro Storm Drain	134-01	4	0-0.1	46	100	53	41,000	<0.4	21,000
Upper Metro Storm Drain	140-01	5	0-0.2	3,900	89	69	27,000	1.8	25,000
Upper Metro Storm Drain	147-01	6C/D	0-0.1	15	370	<8	730	<0.4	86,000
Lower Metro Storm Drain	121-01	4	0-0.1	7.1	220	66	3,300	<0.4	92,000
Lower Metro Storm Drain	125-01	4	0-0.2	25	280	19	750	<0.4	110,000
Lower Metro Storm Drain	126-01	4	0-0.2	110	<0.1	8.0	40	<0.4	40
Lower Metro Storm Drain	128-01	4	0-0.2	3.8	22	<8	1,300	1.3	27,000
Lower Metro Storm Drain	131-01	4	0-0.1	9.2	100	<8	57	<0.4	26,000
Lower Metro Storm Drain	145-01	4	0-0.1	130	0.11	<8	91	0.8	21
Lower Metro Storm Drain	173-01	4	0-0.1	3.8	10	<8	98	<0.4	1,400
Lower Metro Storm Drain	174-01	7	0-0.1	160	<0.1	<8	23	2.2	21
Lower Metro Storm Drain	132-01	7	0-0.1	45	0.15	10	57	1.3	22
Manganese Stockpile	505-01	1	0-0.1	3.7	470	100	370,000	<0.4	150,000
Manganese Stockpile	184-01	2	0-0.1	8,900	1,800	71	900,000	<0.4	660,000
Manganese Stockpile	117-01	3	0-0.1	9.3	<0.1	<8	<6	<0.4	86
Manganese Stockpile	151-01	5	0-0.2	12	26	14	8,100	1.3	21,000
Manganese Stockpile	186-01	5	0-0.3	20	2,000	9.0	42,000	6.7	670,000
Colorado Tailings	113-01	1	0-0.2	34	<0.1	<8	7.0	<0.4	20
Colorado Tailings	111-01	6A/C	0-0.1	9.8	360	<8	150	<0.4	39,000
Area West of Colorado Tailings	100-01	4	0-0.1	12	350	<8	23,000	<0.4	70,000

KEY

Material Unit No.	Material Type	Material Unit No.	Material Type
1	Exposed Tailings	6C	Sleg and Slag Sand and Gravel
2	Covered Tailings	6D	Demolition/Land-fill Debris
3	Manganese Flue Dust	6E	Waste Rock
4	Alluvium/Tailings	7	Exposed Native Soil
5	Railroad Bed Fill	8	Covered Native Soil/Sediment
6	Transported Fill	8A	Organic Silt and Clay, including peat
6A	Sand, Gravel, Colluvium	8B	Sand, Gravel, and Silt (upper two feet)
6B	Manganese Ore Piles	8C	Sand, Gravel, and Silt (below unit 8B)

Source: CH2M Hill and Chen-Northern, 1990

Table 2-5

**SUMMARY OF WATER SOLUBLE METALS FOR SUBSURFACE MATERIALS
AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION**

LITHOLOGIC				CONCENTRATION (µg/L)					
AREA	SAMPLE NO.	UNIT	DEPTH (feet)	As	Cd	Cr	Cu	Pb	Zn
Upper Metro Storm Drain	134-03	4	1.3-2.5	280	290	81	820,000	<0.4	33,000
Upper Metro Storm Drain	606-09	6C	2.0-5.5	<3	73	<8	270	4.8	20,000
Upper Metro Storm Drain	811-18	2	22-25.3	140	1.8	<8	1,700	8	640
Upper Metro Storm Drain	814-10	8C	12-20	<3	6.3	<8	690	0.4	810
Upper Metro Storm Drain	GW-GS-50	8C	162-164	<3	0.48	<8	<8	<0.4	83
Upper Metro Storm Drain	GW-GS-50	8C	166-167	<3	0.83	<8	11	<0.4	70
Upper Metro Storm Drain	GW-GS-50	8C	168-176	<3	<0.1	<8	47	<0.4	120
Upper Metro Storm Drain	GW-GS-50	8C	242-244	29	<0.1	<8	<8	<0.4	28
Upper Metro Storm Drain	GW-GS-50	8C	244-248	44	<0.1	<8	<8	0.89	68
Upper Metro Storm Drain	GW-GS-50	8C	245	51	<0.1	<8	<8	<0.4	87
Upper Metro Storm Drain	GW-GS-50	8C	270	9.8	0.52	<8	<8	<0.4	18
Lower Metro Storm Drain	123-01	4	0-1.2	4.9	66	<8	660	<0.4	11,000
Lower Metro Storm Drain	173-04	4	1.7-2.4	5.3	0.72	<8	140	2.2	310
Lower Metro Storm Drain	175-02	7	0.2-1.5	12	0.86	<8	54	42	300
Lower Metro Storm Drain	182-05	8A	7.0-7.8	120	12	<8	32	<0.4	6,200
Manganese Stockpile	152-03	2	2.8-3.7	16	240	<8	520,000	2.0	100,000
Manganese Stockpile	507-11	2	2.0-3.5	24	40	18	300	10	14,000
Manganese Stockpile	506-11	4	6.0-9.5	18	180	14	6.0	800	23,000
Manganese Stockpile	509-09	4	0.8-2.8	23	4,100	25	330,000	15	740,000
Colorado Tailings	112-05	2	2.4-2.8	86	120	<8	170,000	5.4	39,000
Colorado Tailings	516-10	2	1.0-3.0	23	31	9	180,000	9.8	7,000
Colorado Tailings	518-04	8A	1.5-2.5	9.5	330	<8	100	0.9	22,000

KEY

Material Unit No.	Material Type	Material Unit No.	Material Type
1	Exposed Tailings	6C	Slag and Slag Sand and Gravel
2	Covered Tailings	6D	Demolition/Land-fill Debris
3	Manganese Flue Dust	6E	Waste Rock
4	Alluvium/Tailings	7	Exposed Native Soil
5	Railroad Bed Fill	8	Covered Native Soil/Sediment
6	Transported Fill	8A	Organic Silt and Clay, including peat
6A	Sand, Gravel, Colluvium	8B	Sand, Gravel, and Silt (upper two feet)
6B	Manganese Ore Piles	8C	Sand, Gravel, and Silt (below unit 8B)

Source: CH2M Hill and Chen-Northern, 1990

Significant concentrations (above the MCL of 50 µg/l) of arsenic were leached from railroad bed fill; alluvium/tailings; covered tailings; exposed contaminated soils; buried contaminated silt, sand and gravel, and organic-rich silt and clay. Significant concentrations of cadmium (> 5 µg/l) were leached from alluvium tailings; railroad bed fill; slag and slag sand and gravel; demolition/land-fill debris; exposed and covered tailings; contaminated sand, gravel, colluvium, and organic silt, clay and peat. For chromium, only exposed tailings leached concentrations equal to or greater than the MCL value of 100 µg/l. Exposed and covered tailings; mixed alluvium and tailings, and railroad bed fill materials leached copper concentrations above 1,000 µg/l. Lead in excess of the 50 µg/l MCL was leached only from one manganese stockpile sample. Exposed and covered tailings; mixed alluvium and tailings, railroad bed fill; contaminated sand gravel, colluvium; slag and slag sand and gravel; demolition/land-fill debris, and organic silt, clay and peat leached zinc concentrations above the SMCL value of 5,000 µg/l (CH₂M Hill and Chen-Northern, 1990 Chapter 4, Volume I).

A water leach is a relatively mild leach and does not simulate leaching of source materials with more aggressive solutions such as acids from the formation of acid mine drainage. In the Phase I RI for Silver Bow Creek area (MultiTech, 1987), a number of extractions were performed on the solid samples, including: saturation extract (paste method); 1.0N ammonium acetate extract; and Olsen (sodium bicarbonate) or Bray (ammonium fluoride+hydrochloric acid) extraction for arsenic and phosphorous (see MultiTech, 1987, Table 2-2, Appendix B, Part 1). Results for these extractions were presented by MultiTech (1987, Appendix B, Part 4). Maximum concentrations of soluble metals were generally found either at the surface or at the base of tailings or occasionally in soil directly below tailings. Extractable metal levels were often highest in soils just below the tailings.

Surface salts (efflorescent salts on tailings piles) in the Ramsay Flats area, which are also present along Silver Bow Creek in Area I OU, had extremely elevated concentrations of soluble and total metals, low pH values (2.8 to 3.9) and high specific conductance values. Soluble metal concentrations (mg/kg) ranged from 1,030 to 2,320 (Cu); 383 to 980 (Zn); 0.36 to 7.03 (Fe); 11.8 to 449 (Mn); 0.977 to 4.23 (Cd), and 0 to 0.13 (Pb). Total metal concentrations (mg/kg) ranged from 65,500 to 98,500 (Cu); 22,200 to 31,200 (Zn); 4,140 to 9,700 (Fe); 7,500 to 1,9700 (Mn); 48.3 to 120 (Cd), and 25.8 to 149 (Pb) (MultiTech, 1987, Appendix B, Part 4, Att. VI-C, samples 26, 27, 29). Metals in efflorescent salts are extremely soluble and are significant metal contamination threats to shallow groundwater in a number of locations along Silver Bow Creek in Lower Area I.

EP Toxicity leaches were performed on materials in Area I OU (CH₂M Hill and Chen-Northern, 1990). This test is performed on waste materials to determine whether it is hazardous (as a waste characteristic) under the Resource Conservation and Recovery Act. The test is designed to predict whether the material can leach significant (100 times the MCL value) concentrations to groundwater or surface waters when it contacts a solution similar to that found in municipal waste landfills (acetic acid mixture). The test is not particularly relevant to mining waste for a number of reasons, including:

- ▶ Organic acids are not often associated with mining wastes (sulfuric acid, for example, may be more appropriate)
- ▶ The length of time that the acid solution is allowed to contact the material for leaching is generally only a small fraction of the time that earth materials would take to leach steady-state concentrations of contaminants to the solution
- ▶ The dilution factor of 0.01 MCL may not be appropriate for evaluating concentrations in groundwater (dilution of this magnitude is common in surface waters).

The results for the EP Toxicity test, nonetheless, do give some kind of lower-end estimate of the concentrations of hazardous substances that could leach from mining wastes in a short time. A number of source materials in the study area have the potential to leach cadmium, lead and arsenic to groundwater at concentrations above their MCL values (Table 2-6).

Hazardous substances can be leached from source materials either in the unsaturated or saturated zone. Infiltration of precipitation or snow melt or rising capillary water from the water table can leach materials in the unsaturated zone. Groundwater flowing through contaminant sources in the saturated zone can likewise leach hazardous substances. Changes in water table level, either seasonally, as a result of artificial recharge or in response to ceasing dewatering operations, can inundate primary or secondary source materials and leach hazardous substances to groundwater. Both primary and secondary sources identified in the study area have been shown to leach significant concentrations of hazardous substances to groundwater.

Formation of acid mine drainage in the underground workings involves a similar leaching of primary source materials that generates significant concentrations of dissolved sulfate, iron, manganese, aluminum and hazardous substances in minewater in the Butte Hill/Berkeley Pit area. The mechanisms for formation of acid mine drainage are discussed in Section 2.1.2.2. The leaching of mineralized material, including efflorescent salts, remaining in underground workings is the primary pathway for contamination of the bedrock aquifer in the Butte Hill/Berkeley Pit area.

2.2.2.2 Transport of Contaminated Water to Groundwater, Pit Water or Surface Water

For this pathway, water contaminated with hazardous substances includes: (1) process solutions from the historic Weed Concentrator and the current MR Concentrator; (2) solutions associated with operation of the leach pads; (3) mine and process water pumped from underground workings and precipitation plant to SBC/MSD; (4) sulfuric acid added to leach copper from underground mines; and (5) contaminated alluvial and bedrock groundwater.

Table 2-6

**SUMMARY OF EP TOXICITY LABORATORY DATA FOR
SURFACE AND SUBSURFACE MATERIALS;
AREA I OPERABLE UNIT PHASE II REMEDIAL INVESTIGATION**

Area	Sample No.	Material Unit	Depth (feet)	CONCENTRATION ($\mu\text{g/L}$)							
				As	Ba	Cd	Cr	Pb	Hg	Se	Ag
Upper Metro Storm Drain Area	611-18	2	22.0-25.3	11	117	<2	<6	<25	<0.15	<1	<7
Upper Metro Storm Drain Area	606-09	6C	2.0-5.5	5	154	44	<6	<25	<0.15	<1	<7
Upper Metro Storm Drain Area	614-10	8C	12.0-20.0	0.6	207	3	<6	<25	<0.15	<1	<7
Lower Metro Storm Drain Area	123-01	4	0.0-1.2	9.6	80.5	110	<5.5	33.2	<0.15	<1.1	<7
Lower Metro Storm Drain Area	179-01	6D	0.0-5.6	161	207	10.8	<5.5	71.3	<0.15	<1.1	<7
Manganese Stockpile Area	505-01	1	0.0-0.1	3	96	300	6	<25	0.4	<1	<7
Manganese Stockpile Area	152-01	2	0.0-1.3	25.0	104	85.7	<5.5	84.6	<0.15	<1.1	<7
Manganese Stockpile Area	507-11	2	2.0-3.5	10	115	23	<6	42	0.4	<1	<7
Manganese Stockpile Area	506-11	4	6.0-9.5	27	31	339	<6	17900*	0.4	<1	<7
Manganese Stockpile Area	509-09	4	0.8-2.8	9	72	1620*	<6	51	<0.15	<1	<7
Manganese Stockpile Area	186-01	5	0.0-0.3	6.6	75.2	917	<5.5	447	<0.15	<1.1	<7
Colorado Tailings Area	515-10	4/8A	12.0-15.5	10	199	277	8	2660	<0.15	<1	<7
Colorado Tailings Area	518-04	8A	1.5-2.5	2	111	1030*	6	<25	0.25	<1	<7
Area West of Colorado Tailings	100-03	4	0.8-1.7	293	112	43.8	<5.5	1310	<0.15	<1.1	<7
Area West of Colorado Tailings	104-02	4	0.1-1.2	31.4	212	131	<5.5	3310	0.86	<1.1	<7

* Exceeds EP Toxicity Maximum Concentrations

KEY

Material Unit No.	Material Type	Material Unit No.	Material Type
1	Exposed Tailings	6C	Slag and Slag Sand and Gravel
2	Covered Tailings	6D	Demolition/Land-fill Debris
3	Manganese Flue Dust	6E	Waste Rock
4	Alluvium/Tailings	7	Exposed Native Soil
5	Railroad Bed Fill	8	Covered Native Soil/Sediment
6	Transported Fill	8A	Organic Silt and Clay, including peat
6A	Sand, Gravel, Colluvium	8B	Sand, Gravel, and Silt (upper two feet)
6B	Manganese Ore Piles	8C	Sand, Gravel, and Silt (below unit 8B)

Source: CH2M Hill and Chen-Northern, 1990

These waters can be transported: (1) through the unsaturated zone to downgradient groundwater in either the alluvial or bedrock aquifers; (2) to the Berkeley Pit; and (3) to surface waters in the Metro Storm Drain and Silver Bow Creek.

Process Waters

The Weed Concentrator was operational from 1964 to 1983; the MR Concentrator has been operational from 1986 to the present. Groundwater mounding and changes in groundwater level correspond to active and inactive periods at the Weed Concentrator, indicating that unlined process ponds were and are leaking to the alluvial aquifer (CH₂M Hill and Chen-Northern, 1990). Alluvial groundwater in this area flows into the Berkeley Pit (see Figures 2-4 and 2-5A).

A comparison of water quality of groundwaters and process waters that are ultimately influent to the Berkeley Pit is displayed in Table 2-7. Well AMC-5, located downgradient from the Concentrator, shows elevated concentrations of cadmium, copper, iron, zinc, sulfate and conductivity which likely resulted from transport of process waters from leaking ponds at the Weed Concentrator. More recent samples of AMC-5 are presented in Figures 3-22, 3-24, 3-26, 3-28, 3-30, 3-32 and 3-42 (in CH₂M Hill and Chen-Northern, 1990), and similar elevated levels of hazardous substances are present.

The leach pads have been operational from the 1960s to the present. Alluvial groundwater in this area flows toward the Berkeley Pit, and well LP-03 (well #3 in Figure 2-5) is downgradient from the leach pads area. The composition of water from this alluvial well is shown in Table 2-7 and compared to water from the pregnant and leaching solutions from the leach pad operations. The major ion and metal concentrations, pH values and conductivities of these three solutions are all very similar, indicating, along with groundwater flow directions, that the process waters from the leach pad area are being transported through the unsaturated zone and contaminating groundwater in the Butte Hill alluvial aquifer with hazardous substances.

The composition of the Berkeley Pit water is also shown in Table 2-7 (surface and 400-ft depth). Concentrations of metals and other constituents in the Berkeley Pit are lower in surface water than at depth, most likely as a result of dilution with precipitation, runoff and inflow water (leach water) (CDM, 1988; Davis and Ashenberg, 1989). In almost all cases, concentrations in the lower Berkeley Pit are intermediate between pregnant/leaching solution and Kelley Shaft water concentrations, but the pit water concentrations are much closer to those in the process solutions than in the minewater. Concentrations of contaminants in the Kelley minewater are generally the highest of all the shafts (Table 6.3.1, Canonie, 1992a); therefore, the Kelley composition represents a maximum of minewater input concentration values.

Table 2-7
Water Quality Comparison of Berkeley Pit and Inflow Waters
 (mg/l unless otherwise noted)

Date	Berkeley Pit		Pregnant Solution	Well LP-03	Leaching Solution	Kelley Shaft	Surplus Water	Well AMC-5
	0'	400'						
	May 1991	May 1991	1991 Avg.	1991 Avg.	1991 Avg.	1991 Avg.	1991 Avg.	Dec 1985
pH			2.59	3.18	2.78	5.61	3.11	4.2
Field Cond.*	2.73	2.69	15,900	12,100	8,080	3,700	5,990	2,370
Acidity	6,090	8,050	13,500	10,500	14,200	820	3,230	
Aluminum	274	285	1,450	1,160	1,480	1.80	283	
Arsenic	0.21	0.88	0.3	0.02	0.24	0.90	0.02	< 0.003
Cadmium	1.81	1.57	3.97	5.65	3.36	0.002	2.00	0.49
Copper	178	187	144	297	21.6	0.28	105	20.9
Iron	649	1,100	1,830	677	2,190	277	311	253
Manganese	190	182	451	543	450	50.2	150	
Nickel	1.05	1.06	3.32	3.42	3.11	0.44	0.85	
Zinc	505	506	1,160	1,040	1,240	109	353	96.4
Sulfate	7,220	8,080	37,100	31,300	34,600	1,570	11,500	1,860
Sodium	71.2	69.7	29.4	38.1	29.1	42.0	68.1	51.7
Calcium	473	488	438	387	429	486	0.42	291
Potassium	15.7	20.9	5.99	4.57		29.0	2.56	12
Magnesium	422	420	1,440	1,380	1,500	158	386	53.8
Chloride			51	43.2				14.6
Fluoride	32.9	18.0	125	267	101		70.2	0.58
Silicon (as SiO ₂)	100	98.5	103	14.4	111		71.8	

Sources:

1. Canonie, 1992a: Tables 3.3.2, 7.5.2, 6.3.1. Data are for filtered samples.
 2. Canonie, 1992a: Tables D.1 and 9.2.1. (MBMG data).
 3. MultiTech, 1987. Appendix B, Part 4, Attachment VI (AMC-5).
- * Field Conductivity in $\mu\text{mhos/cm}$.
 1991 Avg. = Average of May and August 1991 data (avg. $\text{pH} = -\log((\text{H}^+ + \text{H}^+_{\text{b}})/2)$).

CDM (1988) estimated that 3.1 mgd of bedrock groundwater and 0.55 mgd of alluvial groundwater were flowing into the Berkeley Pit from 1985 to 1987. At that time 3.60 mgd of precipitation plant discharge (surplus water) was also estimated to flow into the pit (see Table 3.2.1, Canonie, 1992a). In 1991/92, Canonie estimated that only 1.50 mgd of surplus water from the precipitation plant was flowing into the pit, and the volume of minewater (bedrock seepage) was not estimated (see Table 3.4.1, Canonie, 1992a). It may be assumed that the volume will have decreased because of decreased hydraulic head into the pit as a result of rising water levels in the pit (however, Canonie estimates that the bedrock aquifer contributes 3.5 mgd to the pit — 1992a, pg. 61). Concentrations of contaminants in Berkeley Pit water based on concentrations in inflow water are difficult to predict at this time because of uncertainties in the volume of inflow waters. In addition, dissolution, precipitation and other geochemical reactions in the pit and involving the pit walls may affect final pit water chemistry, and these reactions have not been specifically described.

It is apparent, however, from the comparison of Berkeley Pit water chemistry with that of inflow waters, that minewater composition does not adequately explain the observed chemistry of the pit water. Inflow of contaminated surface water and process water has had an effect on the composition of the pit water. Reactions involving the pit walls may also add hazardous substances to the Berkeley Pit water.

Alluvial groundwater containing hazardous substances along Silver Bow Creek in Lower Area I may contaminate the underlying bedrock aquifer. The top of the bedrock aquifer west of Montana Street is much closer to the ground surface than the bedrock east of this area. High concentrations of certain metals are in groundwater in the bedrock aquifer at the west end of the Colorado Tailings. This may indicate that contaminated groundwater from the alluvial aquifer is being transported to the underlying bedrock aquifer (CH₂M Hill and Chen-Northern, 1990). Wells BMW-2B and BMW-4B are completed in bedrock directly below the Colorado Tailings (see Plate I) and show extremely elevated concentrations of copper, zinc, sulfate and other hazardous substances. Concentrations in BMW-2A and BMW-4A in the alluvial aquifer above also show very elevated concentrations of hazardous substances, and in this area contamination from tailings has likely reached the bedrock aquifer.

Directly downgradient of the Colorado Tailings, the alluvial aquifer groundwater discharges to and further contaminates Silver Bow Creek with hazardous substances. Groundwater quality below the Colorado Tailings degrades significantly from south to north and from east to west (Duaine et al., 1984 as cited in MultiTech, 1987). Groundwater discharges to sections of Silver Bow Creek below Montana Street and to the lower reaches of the Metro Storm Drain from about Harrison Avenue to Blacktail Creek.

Sulfuric acid was added to minewater for underground leaching of copper (Spindler, 1977; Spindler, 1992). The extent of injury from the addition of sulfuric acid is unknown; however, the presence of sulfate in reducing portions of the bedrock aquifer in Butte Hill may be explained by the addition of sulfuric acid for underground leaching. Another possible source

of groundwater contamination in this area is the discharging of untreated minewater from underground workings to Silver Bow Creek, which occurred from the late 1800s and continued at least until the 1960s (Spindler, 1977).

2.2.3 Mobility of Hazardous Substances

The mobility of hazardous substances in aquifers is a complex function of hydrodynamic and biogeochemical processes and conditions, including recharge locations, infiltration rate, hydraulic gradient, groundwater velocity and flow patterns, discharge locations, permeability, solubility, precipitation, adsorption, desorption, oxidation/reduction and other reactions.

Available data and observations can be assembled to gain an overall understanding of the mobility of hazardous substances in the Butte area aquifers. Canonie is constructing a model of contaminant migration in the bedrock and alluvial aquifers for the Berkeley Pit area that will consider sources of hazardous substances, groundwater flow patterns and geochemical factors (Canonie, 1992a).

2.2.3.1 Hydrodynamic Considerations

The groundwater flow patterns for the alluvial and bedrock aquifer in the study area have been discussed in previous sections and are displayed in Figures 2-3, 2-4, and 2-5. Areas of contaminated alluvial groundwater (discussed in more detail in Sections 3.2.1 and 3.2.2) are located downgradient of known sources of hazardous substances, which indicates considerable mobility of metals, metalloids and sulfate from sources to groundwater resources. The groundwater plume associated with sources in the upper MSD area has migrated to a greater extent than those plumes associated with sources in Lower Area I.

One of the hydrodynamic factors that determines the extent of the plumes is the proximity of hazardous substance sources to groundwater discharge locations. In the upper MSD area, groundwater does not discharge to surface water until it reaches Harrison Avenue in the lower MSD area, thereby providing a longer lateral stretch for contamination of the alluvial aquifer. In Lower Area I, groundwater discharges to Silver Bow Creek below Montana Street where the bedrock-alluvial interface is closer to the ground surface, forcing groundwater upward into Silver Bow Creek. Groundwater contaminated with hazardous substances from the Butte Reduction Works area, on the north side of Silver Bow Creek, and the Colorado Tailings discharges in relatively short order to Silver Bow Creek, thereby limiting the lateral extent of the groundwater plume but significantly impacting surface water in the creek.

MultiTech performed a study of hazardous substance transport in tailings in the Ramsay Flats area (MultiTech, 1987, Chapter 3); the results are discussed earlier in this report (Section 2.2.2). Generally, except for iron and arsenic, metal concentrations decreased with depth in

the lysimeter samples in the tailings. MultiTech concluded that either little downward groundwater movement was occurring, or metals were immobilized near the base of the tailings. The year MultiTech conducted these experiments (1985) was a below-normal rainfall year, and consequently the soil water potential gradient (downward movement) was very low. They felt that the low gradient, rather than immobilization of metals, explained the segregation of the unsaturated and the saturated zone. When MultiTech modeled an increase in rainfall at 30% above normal, substantial drainage from the unsaturated zone was predicted.

The lithology of the alluvial aquifer is very heterogeneous, resulting in extremely variable hydraulic conductivities and transmissivities. Most groundwater appears to flow through discontinuous sand and gravel lenses. Many of the low-lying areas are thought to be underlain by an organic-rich layer (CH₂M Hill and Chen-Northern, 1990), although this has not been substantiated in many areas. Organic-rich silts have low hydraulic conductivity and transmissivity and, if present, could limit groundwater and hazardous substance mobility below tailings deposits. However, groundwater contamination in the upper MSD area has migrated below the organic-rich layer, which is known to occur at depths of ~20 feet (see CH₂M Hill and Chen-Northern, 1990, Vol. 1, Fig. 4-18).

2.2.3.2 Geochemical Considerations

Geochemical reactions can either limit or enhance the mobility of a hazardous substance in the groundwater resource. Dissolution (leaching) and desorption reactions will cause migration of hazardous substances, while precipitation and adsorption reactions will limit the mobility of hazardous substances in groundwater aquifers. Oxidation and reduction reactions can either enhance or limit the mobility of hazardous substances, depending on the dissolved species produced by the redox reactions. Geochemical reactions specific to the identified hazardous substances are discussed below.

Dissolution/precipitation reactions. Dissolution reactions have been discussed in Section 2.1.2.2 (dissolution of pyrite, other sulfides and aluminosilicates in the mined portions of the Butte Hill bedrock aquifer) and Section 2.2.2.1 (leaching of sources of contamination). Dissolution reactions are responsible for the generation of high concentrations of arsenic, cadmium, copper, lead, iron, manganese, zinc, sulfate and other hazardous substances. Precipitation reactions have been discussed in Section 2.1.2.2. Precipitation reactions can limit the concentrations and/or mobilities of contaminants in the study area. Metal/metalloid and sulfate concentrations can vary with pH and/or the redox state of the water.

The major solubility control for oxidized dissolved arsenic (arsenate, As(V)) is scorodite (FeAsO₄·2H₂O), which controls arsenate solubility between a limited pH range (4-5) (Davis and Ashenberg, 1989), however, scorodite can be transformed to iron hydroxide and dissolved arsenic over time in tailings impoundments (Dove and Rimstidt, 1985). Arsenic in tailings

materials was related in part to sulfide content, and a number of arsenic sulfides are associated with the ore. Under oxidizing conditions, these arsenic sulfides will dissolve and release arsenic to the unsaturated or saturated zone. Extractable arsenic was found 25 inches below the tailings, indicating a fairly high potential for arsenic movement into groundwater (MultiTech, 1987). An aerial deposition source for arsenic (smelter airfall) has been proposed, but the mobility of arsenic from this source has not been evaluated.

MultiTech (1987) argues that copper (Cu) carbonate minerals (malachite and azurite) may control copper solubility above pH 5, and cupric ferrite (CuFe_2O_4) may control copper solubility below pH 5. MultiTech also discusses a possible lead sulfate solubility control for groundwater concentrations of lead.

The low solubility of lead (Pb) sulfate may limit lead mobility in groundwater in the study area because of the high sulfate concentrations associated with contaminated groundwater.

Cadmium (Cd) has moved well below the tailings into underlying soils at Ramsay Flats, and total and exchangeable cadmium concentrations in both upper soil layers and tailings were roughly equivalent (MultiTech, 1987). It is unlikely that significant mineral solubility controls affect cadmium concentrations in the groundwater systems in the study area.

Solubility controls on manganese (Mn) are a strong function of the redox state of the groundwater. Minerals that could limit manganese concentrations in study area groundwaters include pyrolusite, manganite and rhodochrosite (manganese oxide, hydroxide and carbonate, respectively).

Iron (Fe) solubility may be controlled by jarosite (potassium ferric hydroxy-sulfate) below pH 4-5. The fraction of soluble iron in tailings and soils was low, indicating little potential for iron mobilization in groundwaters. Dissolved iron, however, is very widespread in area groundwaters, especially those in the upper MSD area, most likely as a result of the greater solubility of reduced iron.

Aluminum (Al) solubility may be controlled by alunite (potassium aluminum hydroxy-sulfate). Thallium is also a group III metal and is a by-product of purification of cadmium and lead. Thallium sulfate (Tl_2SO_4) has been used as rat poison. TlOH is a soluble weak base.

Ferrous (reduced) iron can decrease the solubility of vanadium (V) by formation of ferrous vanadate, which can exert a solubility control on vanadium in mildly reducing, near neutral to alkaline waters (Hem, 1977). Elevated concentrations of molybdenum occur in Berkeley Pit water (see Section 3.2.1.1). The U.S. EPA has issued irrigation guidelines for molybdenum. As with vanadium, ferrous iron may exert a solubility control on molybdenum between pH 5.3 and 8.3.

Zinc (Zn) concentrations increase with sulfate concentrations, indicating that zinc may be related to the amount of past pyrite oxidation (MultiTech, 1987). Franklinite (a zinc iron oxide) may control zinc solubility below pH 5. At higher pH values, zinc silicates or carbonates may control zinc solubility. Zinc, copper and sulfate occur together in contaminated area groundwaters and appear to have similar mobilities.

As discussed in an earlier section (2.2.2.1) surface salts had extremely high concentrations of total and soluble copper, zinc, manganese and cadmium and are rapidly dissolved upon contact with precipitation and runoff. These salts can also exist in the unsaturated zone where infiltration can leach substantial quantities of metals to shallow groundwater.

Adsorption/desorption reactions. Under the lower pH conditions associated with much of the contaminated groundwater, little metal adsorption can be expected. As pH increases, adsorption of lead, cadmium, zinc, copper and other metals will occur on most natural inorganic solids.

Arsenic behaves nearly the opposite of the metals in terms of adsorption. Unlike most metals, it exists in complexes that are either negatively charged (as H_2AsO_4^- , HAsO_4^{2-} for As(V)) or uncharged (pK_{a1} for H_3AsO_3^0 (As(III)), is 9.3) in most natural waters. Arsenate (As(V)) can adsorb to iron hydroxides and other solids at lower pH values but will tend to desorb at higher pH values. At neutral pH values, selenium, arsenic and antimony concentrations in freshwater environments are controlled by adsorption onto iron and manganese hydrous oxides (Seyler and Martin, 1989; Balistrieri and Chao, 1990; Belzile and Tessier, 1990; and Mok and Wai, 1990).

Cadmium and other metals may be adsorbed to organic-rich silts or peat in the study area. A peat layer ranging from 6 to 24 inches thick underlies most of the Colorado Tailings deposit and thins toward the northwest (Duaine et al., 1982 as cited in MultiTech, 1987). The peat layer below the northwest corner of the Colorado Tailings contains elevated concentrations of total iron, manganese, copper, lead and zinc compared to overlying tailings materials and underlying alluvium (Thornell, 1985 as cited in MultiTech, 1987). The peat layer apparently adsorbs or otherwise immobilizes certain metals leached downward from the tailings deposit. Metals temporarily immobilized in the peat layer may subsequently leach to the unsaturated alluvium and groundwater, and the underlying alluvial aquifer and Silver Bow Creek have been contaminated by hazardous substances leaching from the Colorado Tailings. Organic-rich silt and clay in the study area were shown to contain leachable arsenic and metals (Section 2.2.2.1).

Oxidation/reduction reactions. The following identified substances can undergo oxidation/reduction reactions that will significantly affect their mobility and toxicity: arsenic, antimony, selenium, vanadium, chromium, iron, manganese and sulfate.

Arsenic (As) and antimony (Sb) have similar redox chemistries: both occur as oxyanions with the metalloid in the 3+ and 5+ oxidation states in most natural waters; both can form less toxic methylated species, and both are released from contaminated sediments with increasing pH (Andreae, 1983; Mok and Wai, 1990). Arsenic in Berkeley Pit water was shown to be predominantly As(V) (Davis and Ashenberg, 1989). A nearly opposite distribution of arsenic species was shown in an alkaline saline lake (As(III) concentrations dominate at lake depths where dissolved oxygen is below detection) (Maest et al., 1992).

Selenium (Se) and sulfur (S) have similar chemistries, and both occur as oxyanions with selenium and sulfur in the 4+ and 6+ state in most natural waters. Adsorption of oxidized selenium (Se(VI)) is not pH-dependent, as is the case for other oxyanions, and is considered a strongly-binding anion. Sulfate can be reduced to sulfide by sulfate-reducing bacteria. Formation of sulfide in reducing waters can decrease metals concentrations via precipitation of metal/metalloid sulfides. Apparently, sulfide is not forming to an appreciable extent at depths in Berkeley Pit water, because metal concentrations do not decrease with depth in the pit. The low pH may favor the formation of bisulfate (HSO_4^-) complexes.

Vanadium (V) occurs as both oxyanions and an oxocation in natural waters, with vanadium in the 3+, 4+, and 5+ oxidation states. V(IV) forms strong complexes with organic ligands (Middelburg et al., 1988). The more toxic V(V) can be reduced to V(IV) by *Thiobacillus thiooxidans*, a bacterium associated with acid mine drainage. The oxocation, $\text{V}(\text{OH})^{2+}$, can be complexed by organic matter and adsorb to oxides under high pH, reducing conditions (Domagalski et al., 1990). Elevated concentrations of vanadium occur in Berkeley Pit water (see Section 3.2.1.1).

Chromium (Cr) occurs as Cr(III) and Cr(VI) in natural waters. The oxyanion, chromate Cr(VI), is considerably more toxic than Cr(III). Cr(III) usually occurs as particulates, while Cr(VI) is much more soluble and mobile under oxidizing to mildly reducing conditions.

Iron occurs in the 2+ (ferrous) and 3+ (ferric) oxidation states. The solubility of ferric hydroxides is extremely low in waters with pH values above 3; therefore, reduced iron is much more mobile in most site groundwaters. It is likely that the high concentrations of iron in the alluvial and bedrock aquifers and Berkeley Pit waters are in the reduced form, ferrous iron. Manganese, like iron, is much more mobile in groundwaters in its reduced form, Mn(II). Mn(IV) is very insoluble. Elevated concentrations of iron and manganese in groundwaters, which occur throughout study area groundwaters, indicate reducing conditions or oxygen depletion (Stumm and Morgan, 1981).

2.2.4 Estimated Rate of Transport of Hazardous and Related Substances in Groundwater

As discussed in the previous section, a number of hydrodynamic and geochemical factors can increase or decrease hazardous substance mobility and concentrations in groundwaters. The mobility of hazardous substances in the bedrock aquifer has been complicated by mining-related pumping.

In the alluvial aquifer, especially in the upper MSD area, it is possible to arrive at an estimate for the transport rate of certain hazardous substances. In this area, the major sources — the Parrott tailings and other buried slag and mill waste piles — are associated with the highest concentrations of hazardous substances in groundwater, and the contaminated groundwater plume has decreasing concentrations of hazardous substances in the downgradient direction approximately parallel to the MSD. The highest groundwater concentrations in the upper MSD area are associated with the more northeasterly slag and mill waste dump area shown in Figure 2-1 (from a 1955 aerial photo taken before the wastes were buried). Material in this dump most likely originated from the Parrott Smelter.

Another possible source of groundwater contamination in this area is the discharging of minewater from underground workings, which were pumped in order to lower water levels in the underground mines and the Berkeley Pit, and process water from the precipitation plant. The discharging of untreated minewater and process water to the Metro Storm Drain and Silver Bow Creek began in the late 1800s and continued at least until the 1960s. Silver Bow Creek and MSD water quality was improved to some extent after the installation of the wastewater treatment system, which began operation in 1972 (Spindler, 1977).

Isopleths were drawn for copper, zinc, arsenic, cadmium, lead, iron and sulfate in the upper MSD alluvial aquifer (Figures 3-21, 3-32, 3-41 and 3-42 in CH₂M Hill and Chen-Northern, 1990). CH₂M Hill and Chen-Northern defined the upper aquifer as the upper 10 feet of the alluvial aquifer system, and the lower aquifer as between 10 and 40 feet below water level. Isopleths were drawn for each substance listed above for the upper and the lower alluvial aquifer in Area I.

Using the isopleth maps in CH₂M Hill and Chen-Northern (1990), the distances of greatest extent of the contaminant plumes are determined based on the distance between the middle of the Parrott Tailings area and the greatest downgradient extent of the following isopleths: copper, 100 µg/l; zinc, 1,000 µg/l; cadmium, 10 µg/l; lead, 10 µg/l; sulfate, 500 mg/l. The arsenic and iron plumes with the greatest extent seem to be associated with the waste dump southwest of Harrison Avenue and northwest of the MSD (Figure 9) instead of the Parrott waste piles, and the middle of this waste dump was used to estimate the extent of the arsenic and iron plumes. The 10 µg/l isopleth was used for arsenic, and the 1,000 µg/l isopleth was used for iron. The distances of greatest extent of the contaminant plumes, taken approximately parallel to the MSD, are: copper = 5,500 feet (lower aquifer); zinc = 5,600 feet

(lower aquifer); arsenic = 1,750 feet (upper aquifer); cadmium = 5,400 feet (lower aquifer); lead = 1,250 feet (lower and upper aquifer); iron = 4,000 feet (upper aquifer), and sulfate = 6,400 feet (lower aquifer).

The groundwater chemistry samples for the Phase II RI were collected in 1988-1989, some 108 years after the beginning of operation of the Parrott smelter. The midpoint of the source application is estimated to be the year 1900. By dividing the lateral extent of the contaminant plumes (as described above) by the time since disposal of the source material (88 years), the following estimated order of transport rates is derived (fastest rate to slowest rate of transport):

sulfate > zinc \approx copper \approx cadmium > iron > arsenic > lead.

The estimated rates of transport for these contaminants in upper MSD area plumes are:

Sulfate	=	72.7 ft/yr
Zinc	=	63.6 ft/yr
Copper	=	62.5 ft/yr
Cadmium	=	61.4 ft/yr
Iron	=	45.5 ft/yr
Arsenic	=	19.9 ft/yr
Lead	=	14.2 ft/yr.

It is also likely that the discharge of untreated minewater to the MSD contributed to the extent and concentration of hazardous substances in the groundwater plumes. The midpoint of application of untreated minewaters would be later than 1900 and would thus result in faster transport rates for the above hazardous substances.

3.0 GROUNDWATER INJURY QUANTIFICATION

3.1 BASELINE CONDITIONS

3.1.1 Rationale for Selecting Control Sites

The following criteria were established to determine baseline groundwater conditions in the alluvial and bedrock aquifers:

- ▶ Similar geology to that of impacted areas
- ▶ Similar groundwater flow patterns and system to those of impacted areas
- ▶ Location of baseline wells away from obvious sources of contamination and associated plumes
- ▶ Consideration of groundwater type and other geochemical indicators that may distinguish uncontaminated from contaminated groundwater.

3.1.1.1 Similar Geology

Bedrock Aquifer. Wells for determining baseline water quality conditions in the bedrock aquifer were completed in both the weathered (Silver Bow Creek area wells; Hebgen; residential wells 93-69, 93-73, 93-83) and the competent quartz monzonite (wells A, B, C, D-1, D-2, E, F). Residential well 93-70 was completed in unweathered rhyolite. The distinction between weathered and competent bedrock is operationally defined based on the color of the rock as reported in the drilling logs: reddish rock is considered to be weathered (oxidation of iron sulfides) and grey rock is considered to be unweathered. The red color may be from residual hematitic oxidation products from iron sulfides with limonite texture (i.e., gossan or leached capping) or from disseminated hematite in a rock that was never mineralized with metal sulfides. As discussed in Section 2.2.1.5, the ore body is zonal in character (see Figure 2-7), and wells completed in different zones may have quite different water quality characteristics. Wells A, B, C, D-1, D-2, E, and residential well 93-83 are in the central zone; Hebgen well and well F are in the intermediate zone; and residential wells 93-69, 93-70, and 93-73 are in the peripheral zone. Although residential well 93-70 is in the Outer Camp and the peripheral ore zone, it is drilled in the rhyolite dike that forms Big Butte; therefore, this well is in unmineralized bedrock. The wells in bedrock along Silver Bow Creek are all in unmineralized bedrock.

Alluvial Aquifer. Only wells completed in Quaternary alluvium or Tertiary sediments were chosen for consideration as being representative of baseline water quality in the alluvial

aquifer. Overlying Quaternary alluvial deposits associated with the historic Silver Bow Creek channel cannot be distinguished from underlying Tertiary valley fill materials.

The composition of the Quaternary alluvium and Tertiary sediments is very heterogeneous in places, with variable percentages of gravel, sand, silt, clay and organic matter. Quaternary alluvium on the north side of the MSD/Silver Bow Creek should be more representative of weathering of the mineralized Butte Hill area than alluvial material on the south side of the drainage because of closer proximity to the central part of the ore body, but no significant differences in composition between the two sides have been observed.

3.1.1.2 Similar Hydrology

Bedrock Aquifer. Groundwater flow patterns for the bedrock aquifer are described in Section 2.2.1.4. All wells considered for baseline water quality for the bedrock aquifer, except the Silver Bow Creek area wells, lie within the zone of concentric water contours where groundwater flow is into the pit. The Silver Bow Creek area bedrock wells are in areas where groundwater flow is generally parallel to or toward Silver Bow Creek.

Alluvial Aquifer. Groundwater flow patterns for the alluvial aquifer are described in Section 2.2.1.4. Wells considered for determining baseline water quality in the alluvial aquifer are located upgradient from known sources of hazardous substances and associated plumes. Baseline wells in the Butte Mine Flooding OU are located upgradient from areas of past and current mining activity.

3.1.1.3 Location Away from Known Sources of Hazardous Substances and Associated Plumes

Although samples taken as close to the contaminated area as possible are most likely to be representative of the geology and hydrology of the contaminated area, baseline groundwater quality must be represented by samples taken away from known sources of hazardous substances and outside of associated groundwater plumes so that pre-mining conditions can be estimated. Contaminated groundwater itself is considered a secondary source of contamination that can adversely affect aquifer materials and surface waters.

In some cases, groundwater contaminated with hazardous substances is laterally or vertically discontinuous in an aquifer, and groundwater samples taken very close to the known impact areas may be representative of baseline conditions. This is especially true in the alluvial aquifer. In this section, water from a number of wells will be eliminated from consideration as being representative of baseline water quality because the samples were taken within known groundwater contaminant plumes and are clearly affected by releases from mining waste source materials.

3.1.1.3.1 Bedrock Aquifer

Butte Hill. Isopleths (equal concentration contour lines) have not and cannot easily be drawn for the bedrock aquifer in the Butte Hill area because of fracture-controlled groundwater flow; therefore, evaluation of the bedrock groundwater samples based on proximity to known contaminant plumes is generally not possible. Most of the Bedrock Monitoring Program (BMP) wells (A, B, C, D-1, D-2, E) are in an area of intensive historic mining activity but are not shafts. The Hebgen well and well F are on the edge of the mined area; residential well 93-69, 93-70, and 93-73 are in the Outer Camp, and well 93-83 is in the East Camp, which are all mined areas. It is possible that all wells/shafts considered for baseline bedrock water quality, except those along Silver Bow Creek, are somewhat impacted by mining because of their proximity to the ore body and past mining activity and the extensive "secondary porosity" created by the underground workings. The secondary porosity allows increased surface area of the mineralized material to be exposed to oxygen and water, forming AMD and secondary soluble salts on the walls and floor of the mine. However, the following wells in the Butte Hill area will be considered for use in determination of baseline water quality: Hebgen Park, BMP wells A, B, C, D-1, D-2, E, F, and residential wells 93-69, 93-70, 93-73, and 93-83. As these wells are in an impacted area, they provide conservative estimates (maximum baseline concentration values) of baseline bedrock groundwater quality. In addition, sulfuric acid was added to minewater for underground leaching of copper (Spindler, 1977; Spindler, 1992). The extent of injury from the addition of sulfuric acid is unknown. It is possible that the added sulfuric acid plume and the acid mine drainage influence could be separated on the basis of sulfur isotopes, but such a study has not been conducted.

Area I. Some of the wells drilled into bedrock in the Silver Bow Creek area can be evaluated in terms of proximity to known areas of groundwater contamination based on isopleth maps in the Draft Phase II RI Report (CH₂M Hill and Chen-Northern, 1990). The following wells in this area were drilled into bedrock: BMW-1B, BMW-2B, BMW-3B, BMW-4B, BMW-5B, BMW-6B, BMW-7B, BMW-8B, BMW-11B, BMW-13B, DW-125 (MF-13), DW-128 and DW-129.

Several of these wells are in known areas of groundwater contaminant plumes: BMW-2B and BMW-4B (both in copper, zinc, arsenic, cadmium, lead, iron and sulfate plumes under the Colorado Tailings); BMW-3B (in zinc, arsenic, cadmium, iron and sulfate plumes under the Colorado Tailings); BMW-6B (in copper, zinc, cadmium, iron and sulfate plumes near the Colorado Tailings), and BMW-7B (in copper, zinc, cadmium, lead and sulfate plumes in the Butte Reduction Works area). No data are presented for BMW-8B, although it is probably within the zinc, cadmium and iron plumes associated with the Butte Reduction Works area. Thus, only wells BMW-1B, BMW-5B, BMW-11B, BMW-13B, DW-125, DW-128 and DW-129 are considered for baseline bedrock water quality sample locations.

3.1.1.3.2 Alluvial Aquifer

Butte Hill. Wells in the Butte Mine Flooding OU alluvial aquifer were drilled to determine the impact of the leach pads on alluvial and pit water quality (Canonie, 1992a). All wells are affected by contamination from the leach pads area and will not be used to determine baseline water quality in the Butte Mine Flooding OU alluvial aquifer. Water quality data from 1982 to 1987 indicate that wells AMC-8, AMC-15 and AMC-25 are outside the area of influence of the leach pads (Canonie, 1992a). Three wells (AW1, AW2, AW3) drilled as part of the NRDA groundwater investigation in alluvium upgradient from most mining activity will also be used to determine baseline water quality (Plate I).

Area I. Isopleth maps for the Area I alluvial groundwater are presented for dissolved copper, zinc, arsenic, cadmium, lead, iron and sulfate by CH₂M Hill and Chen-Northern (1990, Volume I, Figures 3-21 through 3-32 and 3-41 through 3-42). These maps demonstrate that much of the groundwater in the shallow (< 10 feet) and deeper (10 to 40 feet) zones within the alluvial aquifer in the vicinity of the Metro Storm Drain and Silver Bow Creek is contaminated with metals, arsenic and sulfate. Nonetheless, there are wells located outside of the known plumes associated with release of hazardous substances from mining activity that may be used to estimated baseline bedrock groundwater quality.

A lower concentration isopleth (250 mg/l = SMCL for sulfate) could be drawn for sulfate because sulfate concentrations continue to decrease away from both the upper and lower alluvial aquifer sulfate plumes (CH₂M Hill and Chen-Northern, 1990, Figures 3-41 and 3-42). Using an approximated 250 mg/l isopleth for sulfate, which is the plume with the greatest volumetric extent, the only alluvial aquifer groundwater wells in this area that are outside of and upgradient from identified groundwater plumes are GS-20 and MF-4.

3.1.1.4 Groundwater Type

Major ion concentrations of alluvial aquifer groundwater samples were used to classify and characterize groundwater types in the study area. Piper diagrams allow plotting of the relative amounts of cations (Mg, Ca, Na+K) and anions (SO₄, Cl, CO₃+HCO₃) as percentages of milliequivalents per liter. Piper diagrams have the advantage of being able to plot a number of samples on the same diagram, while a different Stiff plot is required for each water sample. Piper diagrams are useful for evaluating mixing and chemical evolution of groundwaters, and as such are an important tool for distinguishing baseline and mining-impacted groundwaters.

Morgan and Winner (1962, as cited in Freeze and Cherry, 1979) and Back (1966, as cited in Freeze and Cherry, 1979) identified domains in the Piper diagrams for classification of groundwaters in terms of major-ion percentages (Figure 3-1). Stiff diagrams and Piper diagrams were used to visually depict differences in groundwater chemistry and are displayed

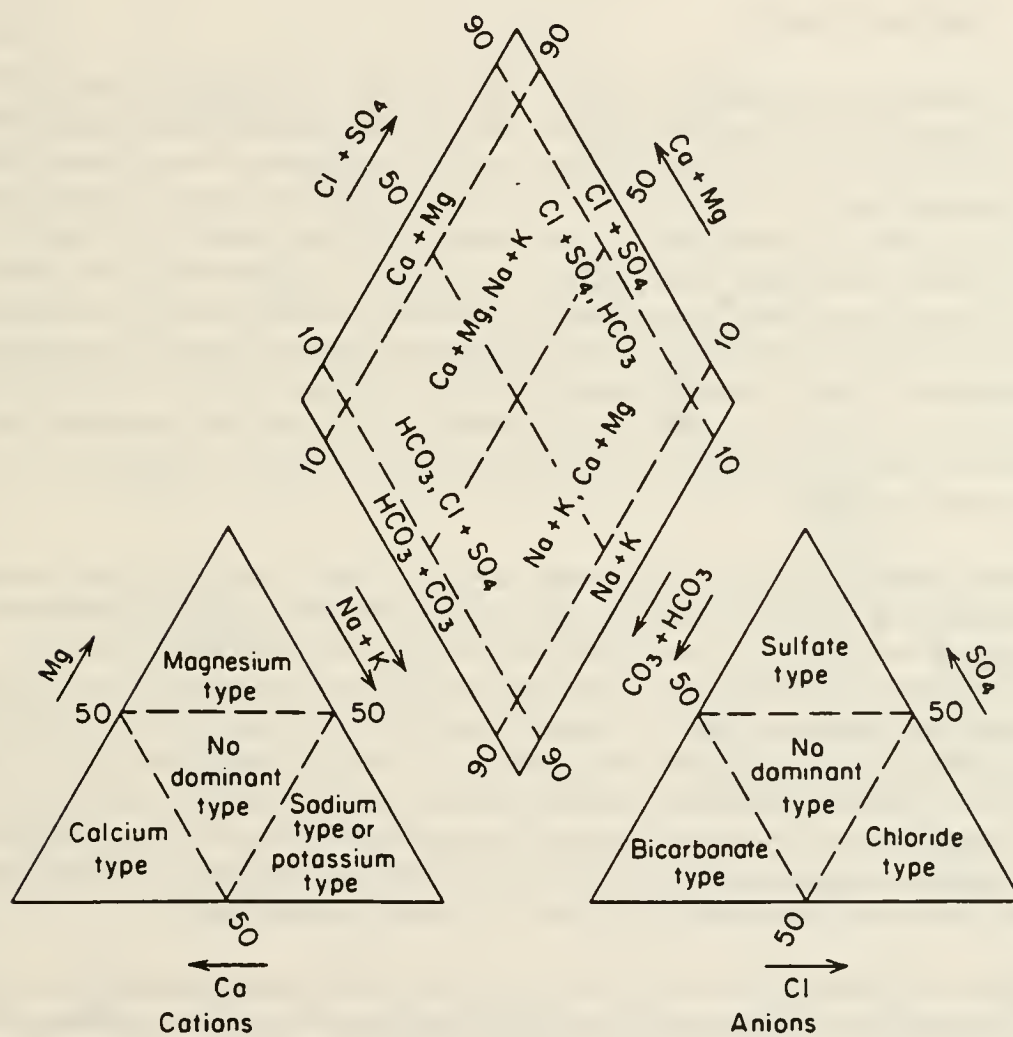


Figure 3-1. Major Cation and Anion Domains for Piper Diagrams. Source: Freeze and Cherry, 1979.

in several reports on the study area (MultiTech, 1987, Appendix B, Part 1, Figures 3-5 through 3-8 and Part 4, page VI-27 through VI-31; CH₂M Hill and Chen-Northern, 1990, Volume 1, Figures 3-39, 3-40; Canonie, 1992a, Figures 7-5 through 7-7; Botz, 1969, Figures 5 and 6). Piper diagrams are presented for selected bedrock groundwater samples in Figures 3-2, 3-3, and 3-4 and for selected alluvial groundwater samples in Figures 3-5 and 3-6.

3.1.1.4.1 Bedrock Aquifer

Butte Hill. Piper diagrams for bedrock aquifer baseline wells in the Butte Hill area are presented in Figure 3-2. Samples from Hebgen Park and the residential wells 93-69, 93-70 (no calcium data available), 93-73, and 93-83 are calcium-sulfate/bicarbonate waters, while all BMP well samples (wells A, B, C, D-1, D-2, E, F) have higher percentages of sulfate and plot as calcium-sulfate type waters (well F is a Ca/Na+K-SO₄ type water). The high percentage of sulfate in the BMP well samples most likely indicates that they have been impacted by contamination from mining activity. However, it is also possible for sulfate to be derived from natural weathering of sulfides under oxygenated conditions (Bassett et al., 1992; Runnells et al., 1992). The pH range of the BMP wells was 5.84 to 7.68 (the pH of 9.25 for well D-2 on August 31, 1994 seems unreliable, because all other pH values for that well were 6.47 to 6.59). Therefore, the groundwater in these wells is not considered to be entirely acid mine drainage.

Bedrock aquifer control sites in Butte Hill are in an area of the ore body that could generate high concentrations of sulfate if exposed to oxygen and water because pyrite is common as a gangue mineral in the central ore zone. However, the Butte Hill control wells are in competent, unweathered, unoxidized bedrock and should not be in a naturally oxidizing zone. Nearby mining and dewatering activities exposed these wells to oxygen and may have caused the observed elevated dissolved sulfate concentrations. The BMP wells (wells A, B, C, D-1, D-2, E, F) will be considered baseline wells with the caveat that they most likely are somewhat contaminated by exposure to oxygen and hazardous substance source materials. Hazardous substance concentrations in these wells therefore are considered maximum baseline concentration values for groundwater in the bedrock aquifer control areas.

The major element chemistry of water in the mine shafts, which can be considered mining impacted, indicates that calcium-sulfate is the predominant water type (see Appendix IIA). Minor amounts of bicarbonate are present in the Anselmo and Belmont shaft. The Granite, Kelley, Lexington, and Steward mine waters show the most pronounced calcium and sulfate concentrations. This is to be expected in mines where oxidation of sulfide minerals results in higher sulfate concentrations. As discussed previously, addition of sulfuric acid, which is a CERCLA hazardous substance, to underground mines (Spindler, 1977; Spindler, 1992) may also have contributed to the concentrations in and extent of the sulfate injury in the area of mining.

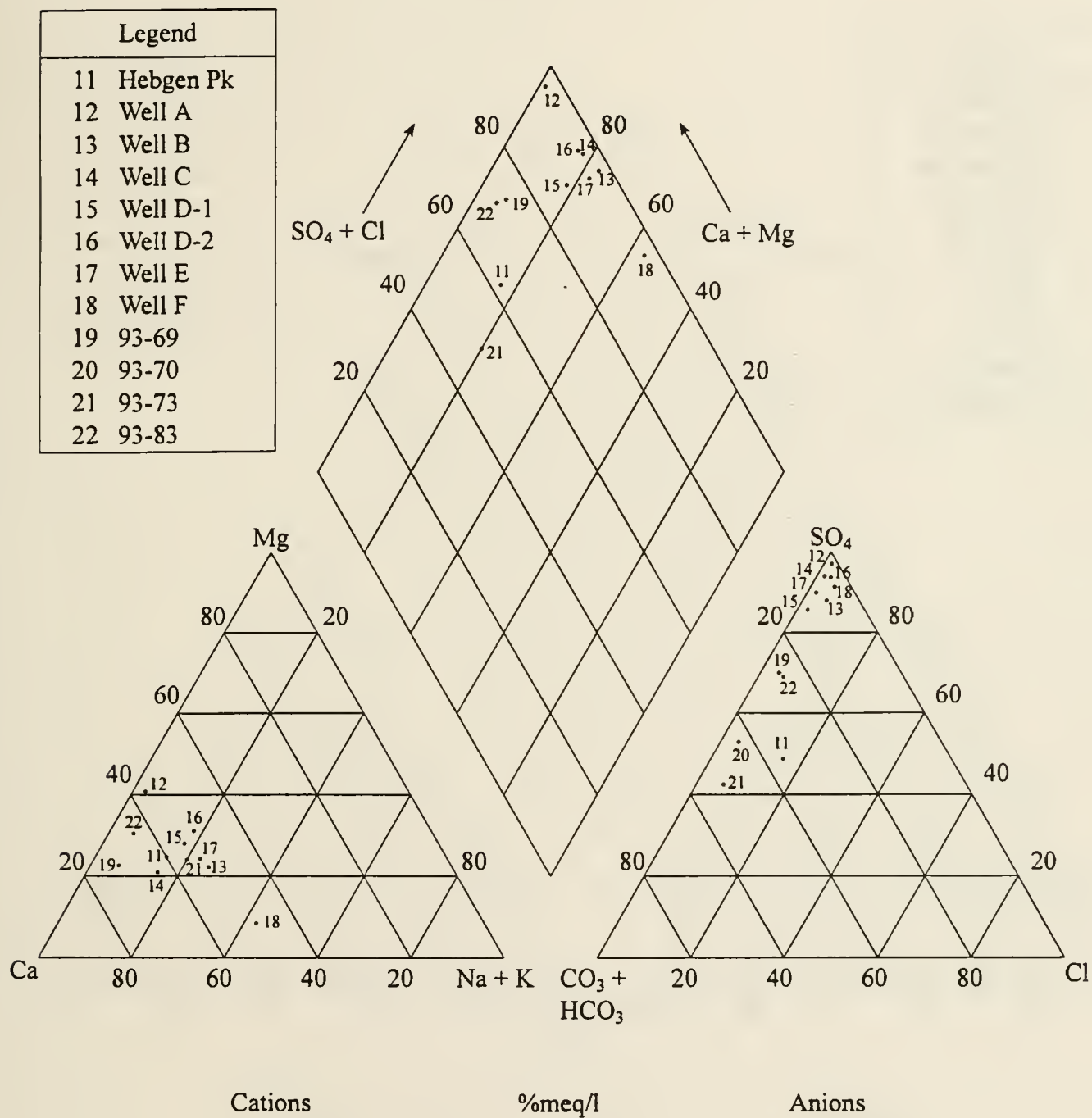


Figure 3-2. Piper Diagrams for Baseline Bedrock Groundwater Wells in Butte Mine Flooding Area.

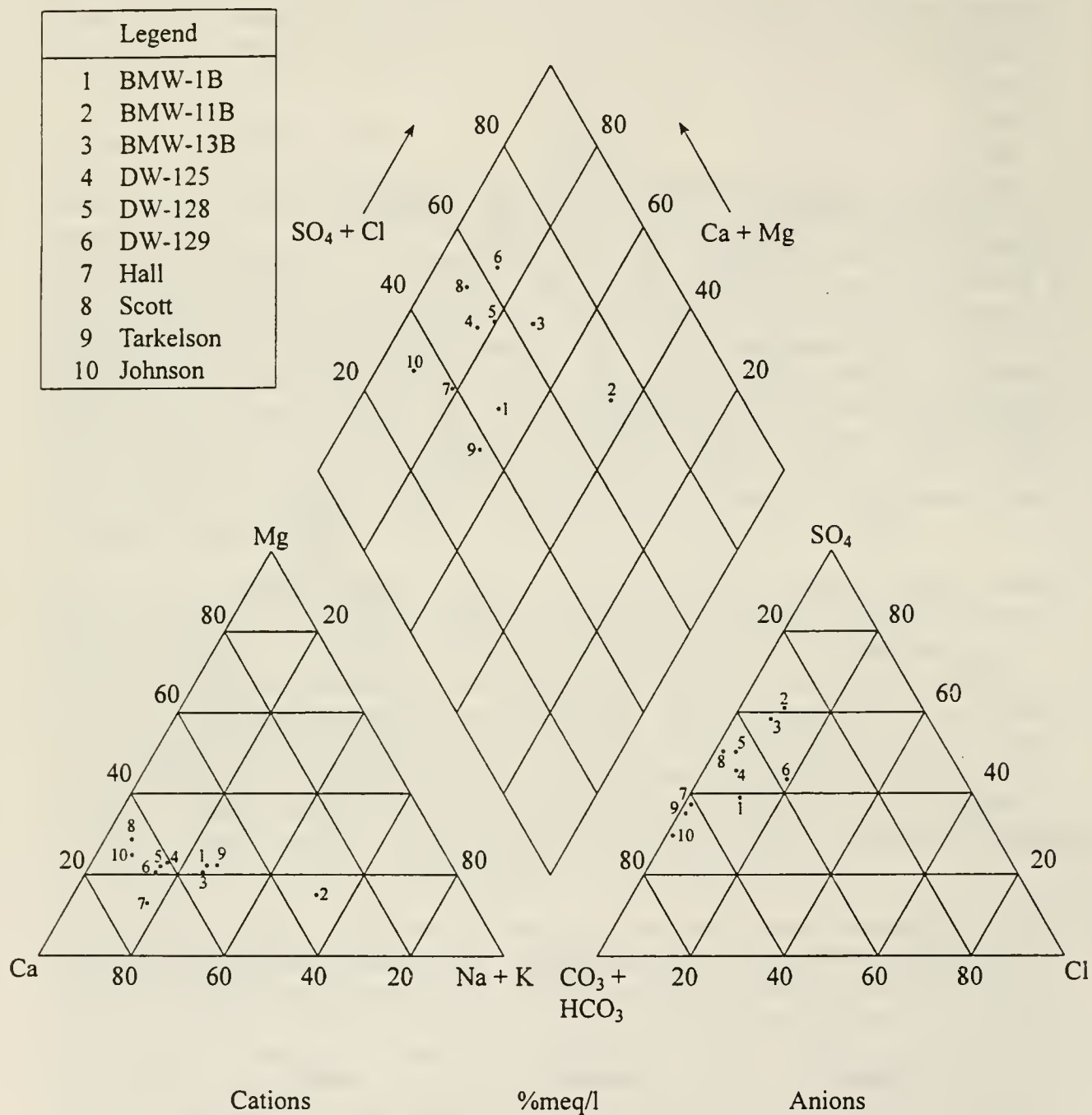


Figure 3-3. Piper Diagrams for Baseline Bedrock Groundwater Wells in Area I.

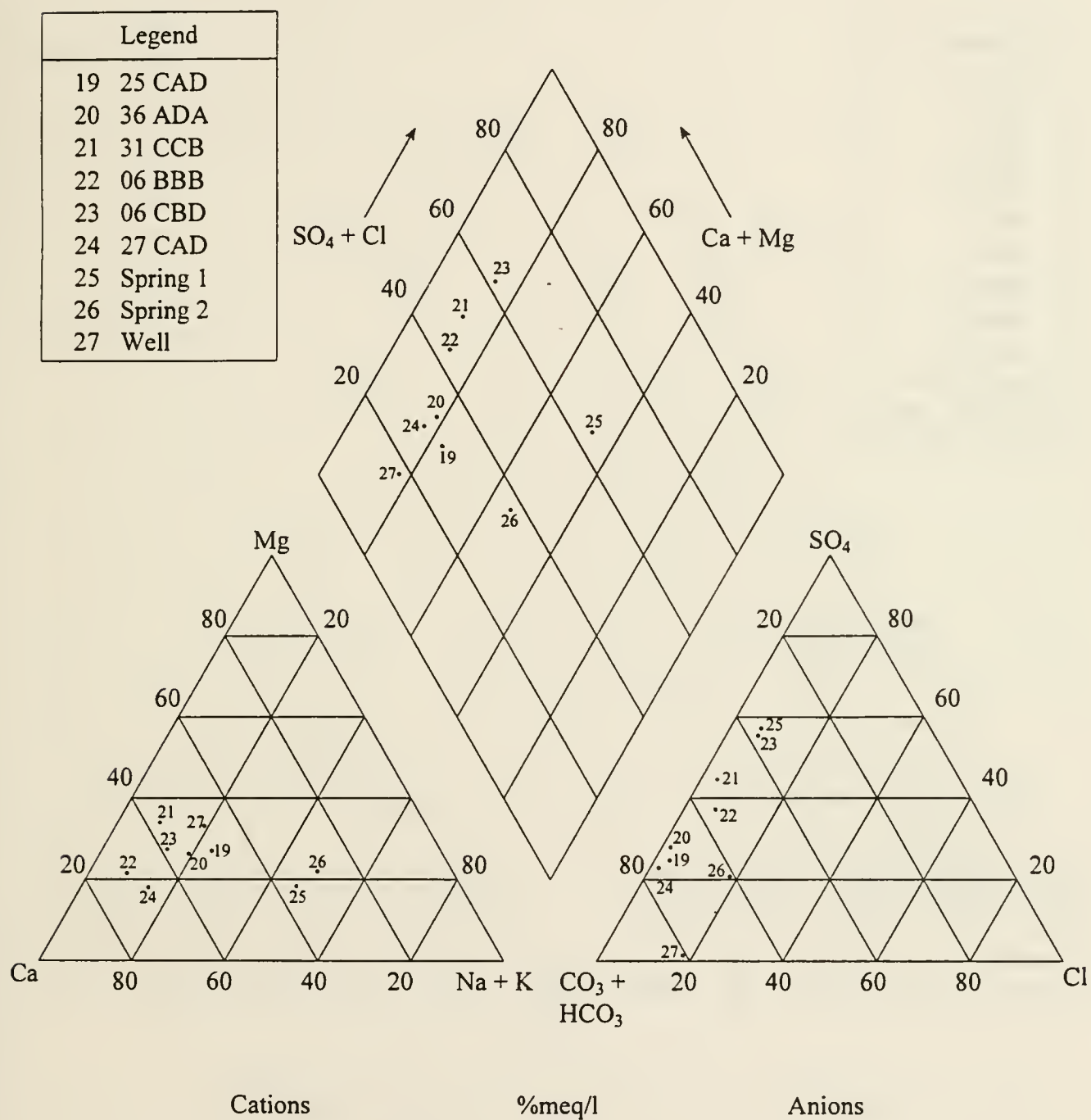


Figure 3-4. Piper Diagrams for Historic Bedrock Groundwater Quality Data.

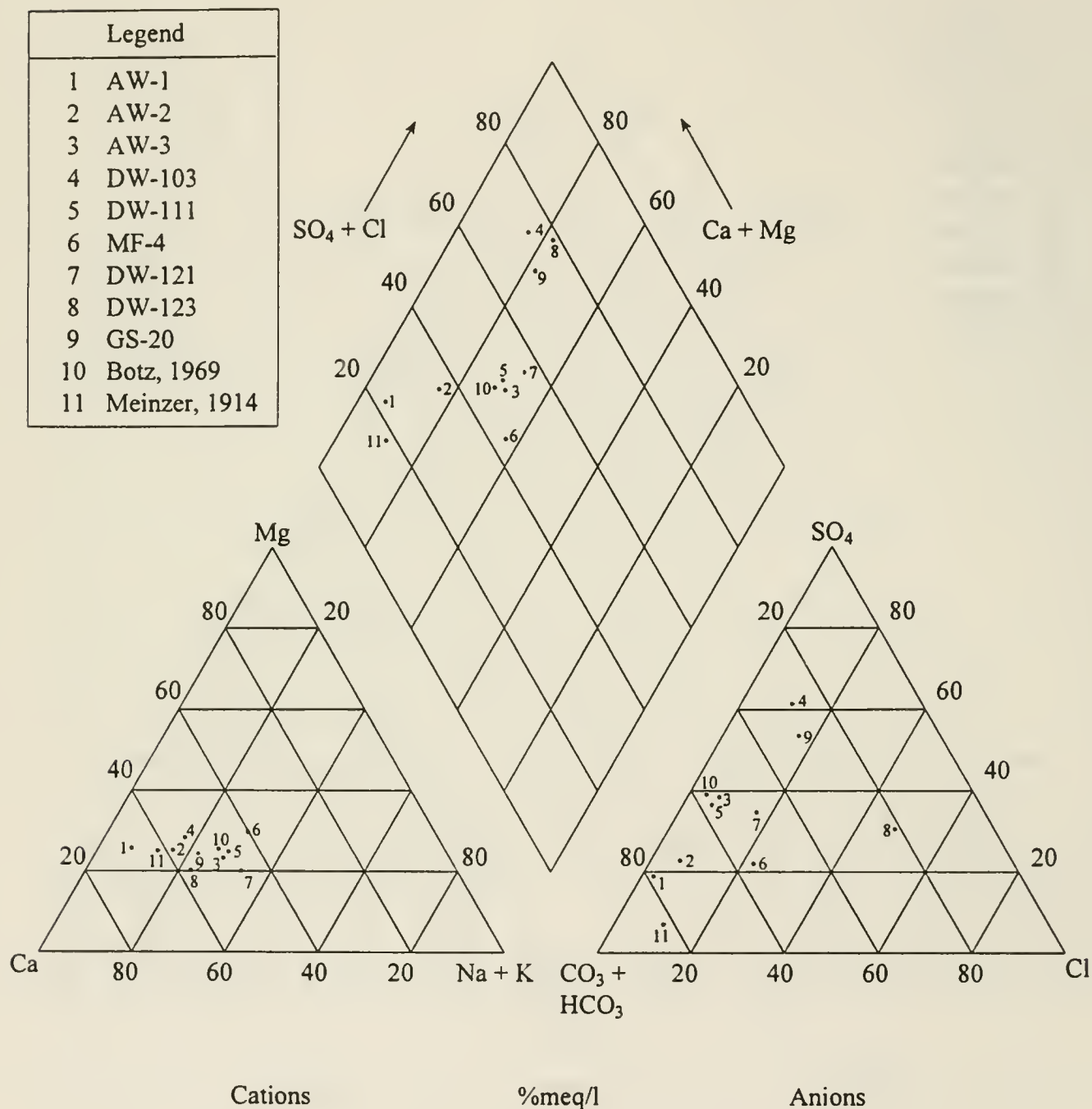


Figure 3-5. Piper Diagrams for Potential Baseline Alluvial Groundwater Wells.

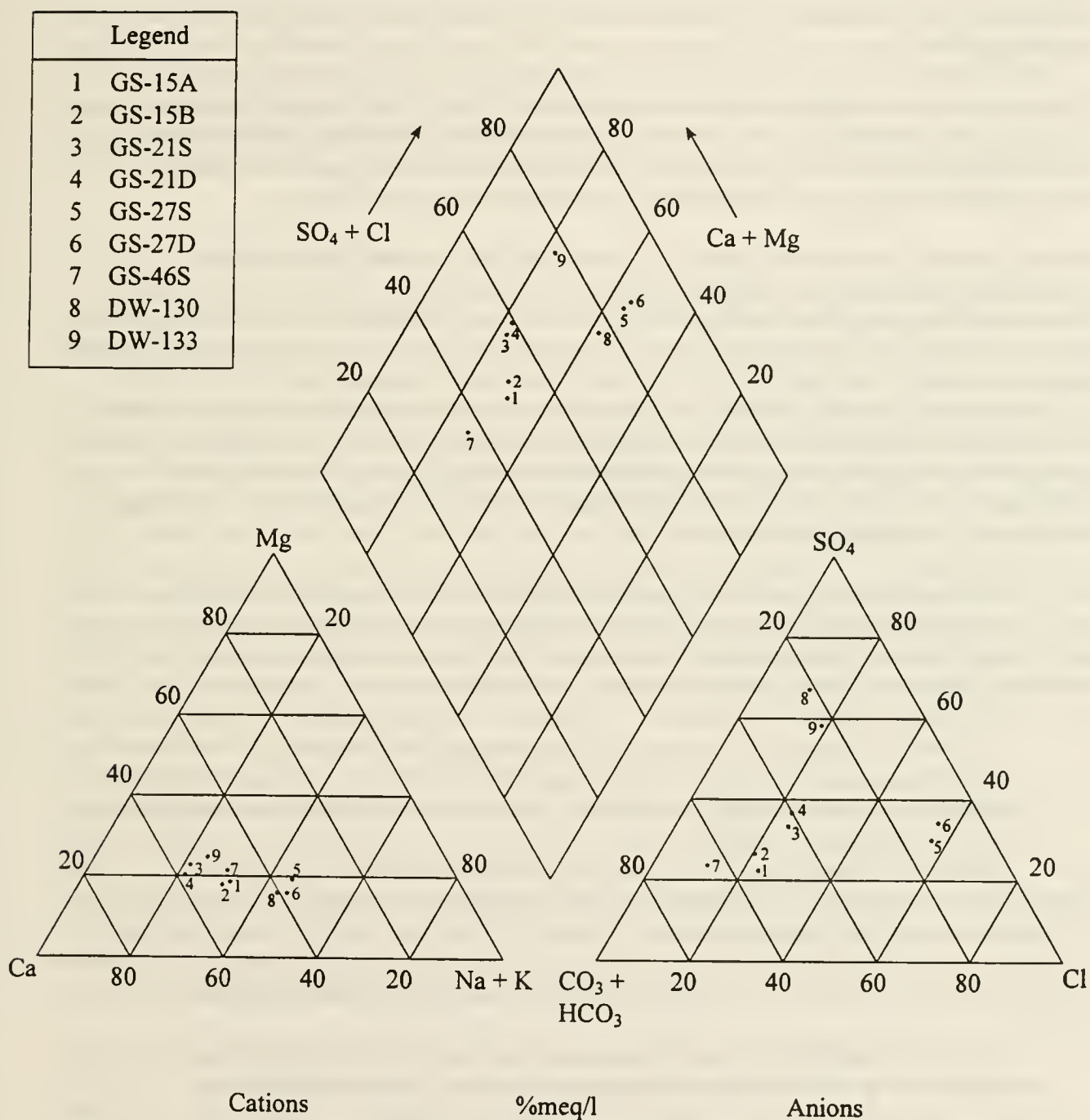


Figure 3-6. Piper Diagrams for Potential Baseline Alluvial Groundwater Wells (continued).

Area I. Piper diagrams for selected bedrock aquifer baseline wells in Area I are presented in Figure 3-3. The groundwaters are predominantly calcium-bicarbonate type waters and can be considered to be representative of baseline water quality for the unmineralized, weathered bedrock aquifer.

The groundwater in all four domestic wells (analyses 7-10 in Figure 3-3) is of calcium-bicarbonate type. The Scott well also contains some sulfate. The Piper diagrams for the domestic wells indicate that groundwaters associated with the Butte quartz monzonite in nonore producing areas are predominantly calcium-bicarbonate type waters.

Historic bedrock groundwater quality. Piper diagrams for selected historic bedrock groundwater quality data are presented in Figure 3-4. Analyses 19-24 are from the upper Silver Bow Creek area (Botz, 1969). Samples 19-21 are well samples from groundwater in quartz monzonite and other granitic rocks, and samples 22-24 are from springs that issue from quartz monzonite. Analyses 25-27 are of water from shallow springs and wells in granitic rocks near Butte (Meinzer, 1914). The piper diagram for the historic bedrock groundwater samples plot similarly to the baseline bedrock groundwater samples in Area I (Figure 3-3). Most of the historic bedrock groundwater samples plotted in Figure 3-4 are calcium-bicarbonate type waters. This groundwater type is most likely representative of baseline groundwater in unmineralized bedrock.

W. H. Weed performed a classic study entitled 'Geology and ore deposits of the Butte District, Montana' (Weed, 1912; these samples are not plotted in Figure 3-4). As part of this study he collected six water samples from the mines in Butte. One sample was collected from the 2,200-foot level of the Green Mountain Mine and was taken to represent:

... as near as practical the composition of the water of the deep levels of the district. It is from a fissure in normal granite remote from any known veins and far from any old mine workings, coming from a fissure tapped by a newly opened crosscut the day before the sample was taken.

This sample contained 407 mg/l sulfate, 13.5 mg/l bicarbonate, 151 mg/l calcium, 1.8 mg/l ferrous iron and 0.5 mg/l manganese.

Another sample was collected from the 800-foot level west of the Anaconda Mine:

It is faintly alkaline and may be assumed to represent the water descending through that great vein at a point beyond the reach of oxidizing influences.

This sample contained lower concentrations of sulfate and calcium: 90.6 mg/l sulfate, 12 mg/l chloride, 11.1 mg/l sodium, 49 mg/l calcium, 3.5 mg/l potassium, 10.3 mg/l magnesium, 0.9 mg/l ferrous iron and 2.5 mg/l manganese.

These results, which can be used only qualitatively, illustrate the presence of waters with elevated sulfate, iron and manganese concentrations in mineralized granitic bedrock of the area. It is possible, therefore, that waters with somewhat elevated sulfate, iron and manganese concentrations from the Butte Hill wells are representative of natural background in the mineralized portions of the bedrock aquifer. Although the analyses by Weed showed elevated concentrations of sulfate, iron and manganese, concentrations of hazardous substances such as copper, lead and arsenic are listed as "trace" and zinc concentrations are below the SMCL of 5.0 mg/l (Weed, 1912).

3.1.1.4.2 Alluvial Aquifer

Piper diagrams for selected alluvial aquifer baseline wells and historic data are presented in Figures 3-5 and 3-6.

Butte Hill. Not enough information is presented to evaluate the groundwater type of wells AMC-15 and AMC-25 (alluvial wells, along with AMC-8, in the Butte Hill area that are outside of the influence of the leach pads). Well AMC-8 (DW-103) is a calcium-sulfate type water, but up to 31% carbonate is also present and the specific conductance is quite low (350 to 440 $\mu\text{mhos/cm}$). There are Phase I RI data for AMC-8 and AMC-15 (DW-106), but no major ion chemistry is presented for recent samples of these wells (Table 7.2.2, Canonie, 1992a lists pH, four metals and sulfate). Stiff diagrams for these wells are presented in Canonie, 1992a (Figure 7-7). Concentrations of all major cations and anions are quite low, indicating that the groundwaters were not affected or were only minimally impacted by contaminated water. Data from the NRDA baseline alluvial wells, AW1, AW2 and AW3 are also plotted on Piper diagrams (Figures 3-5 and 3-6). The groundwaters from the NRDA baseline wells are all of calcium-bicarbonate type.

Area I. Contaminated alluvial groundwater in the MSD and the Upper Silver Bow Creek areas is predominantly of calcium-sulfate type, and Stiff diagrams for these groundwater samples exhibit a "skewed" sulfate component (a "peak" at the sulfate point of the Stiff diagram). Elevated sulfate concentrations are most likely the result of oxidation of pyrite and other sulfide minerals. Piper diagrams for alluvial groundwater in the MSD area show that several wells plot separately from the majority of wells adjacent to the MSD (Figure 3-5, in MultiTech, 1987, Appendix B, Part 1).

The wells that are plotted separately are either a distance from the MSD (DW-111 and DW-115) or are influenced by the relatively uncontaminated Blacktail Creek alluvial system (DW-121). The major ion chemistry of these wells is closer to a calcium-bicarbonate type and may represent the pre-contaminated alluvial groundwater type. A potential mixing trend is shown in the Piper diagram for the MSD groundwater samples that is particularly evident in the anion trilinear diagram (Figure 3-5, MultiTech, 1987, Appendix B, Part 1). Mixing

between end-members of high sulfate (contaminated) and high bicarbonate (uncontaminated) waters may explain the trend.

Piper diagrams for contaminated alluvial groundwater samples in Lower Area I also show that the predominant type is calcium-sulfate with several exceptions. DW-130 has no dominant cation type, but is a sulfate-type water. DW-123 has no dominant anion type (although chloride predominates), but is a calcium-type water. Samples DW-133, GS-15A and GS-15B have no dominant anion type, but do not plot in the sulfate field in the Piper diagram (Figure 3-7, MultiTech, 1987, Appendix B, Part 1).

Samples discussed above that are potentially representative of baseline water quality plot in the calcium-type field in Piper cation diagrams (i.e., they could be calcium-bicarbonate or calcium-chloride type waters) but not very far into the sulfate dominance field in the anion diagrams. Therefore, the anion type of groundwater in the study area appears to be more distinctive than cation type for distinguishing contaminated and uncontaminated groundwater areas.

Those groundwaters that plot on the edge or outside of the sulfate-type dominance field in Piper diagrams, therefore, are either candidates for baseline groundwater quality or represent mixtures of contaminated and uncontaminated groundwater. Samples evaluated in the MultiTech report (1987) in Area I that plot on the edge or outside of the sulfate dominance field in Piper diagrams include: DW-111 (MBMG MF-11), DW-115 (MBMG MF-04), DW-121 (MBMG MF-01), DW-123 (MBMG MF-14 and MP-01), DW-133 (MBMG S-01 and DW-124F), GS-15A (GS-15D) and GS-15B (GS-15S). Of these, only DW-111, DW-115, DW-121 and DW-123 are upgradient of known contaminants plumes and will be considered as representative of baseline water quality.

A number of more recently collected alluvial groundwater samples from Area I were evaluated in the CH₂M Hill/Chen-Northern report (1990). Again, the dominant groundwater type from Stiff or Piper diagrams is calcium-sulfate. A number of samples do not plot in the sulfate dominance field in Piper diagrams even though they are in the vicinity of known contaminant plumes (see CH₂M Hill/Chen-Northern, 1990, Figures 3-21 through 3-32, 3-41, 3-42, 3-47, 3-48), and are either mixtures of contaminated and uncontaminated groundwater or are candidates for baseline groundwater quality: GS-15D, GS-15S, GS-20, GS-21D, GS-21S, GS-27D, GS-27S, GS-46S, and MF-04 (DW-115). Piper diagrams for these samples are presented in Figures 3-5 and 3-6. Sulfate percentages for samples from these wells range from 32 to 49% of total anions (bicarbonate+carbonate, chloride, sulfate). Of these, only MF-04, identified earlier, and GS-20 are upgradient from known contaminant plumes.

Historic alluvial groundwater quality. Historic groundwater quality can be used for qualitative evaluation of groundwater types for contaminated and uncontaminated alluvial groundwater. The average major element composition of 41 groundwater samples (excluding those in bedrock and one well north of Silver Bow Creek in a known area of contamination)

in the Upper Silver Bow Creek/Blacktail Creek area analyzed by Botz (Botz, 1969) shows these groundwaters to be of calcium-bicarbonate type. Average chloride, sulfate and bicarbonate concentrations were 6.95, 51.0 and 93.8 mg/l, respectively (n = 41); while average calcium, magnesium, sodium and potassium concentrations were 30.9, 8.81, 13.2, and 3.29 mg/l, respectively. These historic groundwater quality data represent background for waters away from contamination in the alluvial aquifer.

An early paper by Meinzer (1914) includes analyses of groundwater from Quaternary alluvium in the upper Silver Bow basin near Butte. Results from ten alluvial groundwater samples are presented (Meinzer, 1914, pg. 115). Water from six of the samples was more highly mineralized: one well (Le Toile well) in southern Butte; and water from wells at the Butte "Classification yards" (Butte Reduction works area). The six mineralized samples were excluded because of potential contamination from mining activity. The remaining four alluvial wells contained water that was also of calcium-bicarbonate type, with average calcium, magnesium and sodium+potassium concentrations of 26, 6.58 and 6.25 mg/l, respectively. Average bicarbonate, sulfate and chloride concentrations were 107, 7.3, and 7.25 mg/l, respectively, and average total dissolved solid concentration was 148 mg/l. The four wells are generally in the vicinity of Blacktail Creek and are representative of baseline water quality in the unmineralized, weathered portion of the bedrock aquifer in an area not affected by mining. Because historic data were not validated, water quality data will be used only for qualitative comparisons.

In summary, the above analysis of bedrock and alluvial baseline groundwater type indicates that the presence of elevated concentrations of sulfate is representative of mining-related groundwater contamination in the alluvial and unmineralized bedrock aquifers. For groundwater in mineralized bedrock, sulfate (and iron and manganese in unoxidized portions) may occur naturally. As shown with the historic bedrock groundwater quality, and as will be demonstrated below, elevated concentrations of hazardous metals and metalloids such as arsenic, zinc, cadmium, etc., are representative of mining-related groundwater contamination in the mineralized bedrock aquifer. In addition, some unknown amount of the dissolved sulfate, especially in unweathered mineralized portions of the bedrock aquifer, may be related to exposure of sulfides to oxygen via dewatering and other mining-related activities.

3.1.2 Location and Description of Control Sites

3.1.2.1 Bedrock Aquifer

The following wells are chosen to represent baseline bedrock groundwater quality.

Butte Hill

A	Hebgen Park
B	93-69
C	93-70
D-1	93-73
D-2	93-83
E	
F	

Area 1

BMW-1B	DW-125 (MF-13)	Hall
BMW-5B	DW-128	Scott
BMW-11B	DW-129	Tarkelson
BMW-13B		Johnson

Butte Hill

Wells A, B, C, D-1, D-2, E, F. These wells are located within the Butte Mine Flooding OU. They were installed as part of the RI/FS to verify the direction of groundwater flow and to characterize groundwater quality (Canonie, 1992a; ARCO, 1994). The wells are all screened in competent bedrock in the central zone of the ore body. The well logs contain a description of 'traces of sulfides' up to 20% to 30% sulfides in these wells (Canonie, 1992a). Sulfides are common in the ore-bearing rock in this area. The closest mine shafts to this area are the Pittsmont No. 1, 2, 3, and 4 shafts. The 400-foot level was the shallowest level mined in the No. 1 and No. 4 shaft. The 2600-foot level was the deepest level mined in the Pittsmont No. 4. The Pittsmont shafts have been closed off and no water level information is available. The proximity of these wells to the Pittsmont Mine and the presence of sulfides indicate that they are located in an ore-bearing area. These wells were chosen to represent water quality in the minimally weathered, mineralized bedrock in an area somewhat impacted by mining.

Hebgen Park well. The Hebgen Park well is southwest of the Berkeley Pit and was drilled in 1988 to a depth of 275 feet into the Butte quartz monzonite. The Montana Bureau of Mines and Geology currently monitors the water level in this well as part of the Butte Mine Flooding monitoring program. The well is located in the weathered portion of the bedrock aquifer. The well log describes the rock between 150 to 300 feet (sample depth is 75 feet) as hard red oxidized granite or soft red oxidized granite. It is located in the intermediate zone of the ore body, and was chosen to represent groundwater quality in the weathered, mineralized bedrock.

Residential wells 93-69, 93-70, 93-73, and 93-83. These bedrock wells are also located within the Butte Mine Flooding OU (see Figure 8-3, ARCO, 1994 for location of wells). Well 93-69 was screened at 138-193 feet in weathered, mineralized quartz monzonite and is located in the Outer Camp area in the peripheral ore zone. Well 93-70 is also in the Outer Camp and was screened at 135-175 feet in unweathered, unmineralized rhyolite, which is part of the dike that forms Big Butte. No well logs exist for wells 93-73 or 93-83. However, 93-73 is in the Outer Camp and peripheral ore zone and is likely in weathered, mineralized quartz monzonite. Well 93-83 is in the highly mineralized central ore zone and the East Camp, and is likely also in the weathered quartz monzonite.

Area I

Wells BMW-1B, BMW-5B, BMW-11B and BMW-13B are all in Lower Area I on the periphery of the Colorado Tailings. BMW-1B and BMW-5B are southeast of the Colorado Tailings and south of Silver Bow Creek. BMW-11B and BMW-13B are north of Silver Bow Creek; SMW-11B is north of the Colorado Tailings, while BMW-13B is east of the tailings (see Plate I).

Wells DW-125 (MF-13), DW-128 and DW-129 are all completed in quartz monzonite (MultiTech, 1987, App. B, Part 2, Attach. II-A). Well DW-125 (MF-13) is south of Silver Bow Creek, west of Montana Street and south of I-90. DW-128 is south of Silver Bow Creek and southwest of the Colorado Tailings (not shown on Plate I; see Fig. 1-7A). DW-129 is not shown on any available map but has an official location of T03N R08W S22 DBB (MultiTech, 1987). All bedrock wells in Area I are considered to be in weathered, oxidized, unmineralized quartz monzonite.

Four domestic wells were also used for baseline bedrock groundwater quality (locations not shown on Plate I). The Scott and Johnson wells are located in the Little Basin Creek drainage approximately six miles southwest of the city of Butte. Hall's well is located in the Little Blacktail Creek drainage approximately six miles southeast of Butte. Tarkelson's well is located in the southern part of Butte in an area known locally as the 'flats.' These wells are located in the Butte quartz monzonite, but not in a known mineralized area. The sample depths of the Scott, Tarkelson and Johnson are in unweathered bedrock; the Hall well sampling depth may be in weathered bedrock.

3.1.2.2 Alluvial Aquifer

The following wells are chosen to represent baseline alluvial groundwater quality. Their locations are shown in Plate I.

Butte Hill

AW1
AW2
AW3
DW-103 (AMC-8)

Area I

DW-111 (MF-11)
DW-115 (MF-4)
DW-121 (MF-1)
DW-123 (MF-14)
GS-20

Butte Hill. Wells AW1, AW2 and AW3 were drilled as part of the NRDA investigation. AW1 is located above the Yankee Doodle Tailings impoundment in the very upper reaches of Silver Bow Creek by the Continental Divide. AW2 and AW3 are located west and east, respectively of I-15 toward Helena above Columbia Gardens and are also close to the Continental Divide. Both are completed in Quaternary alluvium.

Well DW-103 (AMC-8) is located southeast of the Berkeley Pit and west of the Continental Pit and does not appear to be impacted by mining activity.

Area I. Wells DW-111 (MF-11) and DW-115 (MF-4) are in the Metro Storm Drain area. DW-111 is located south of the MSD, while DW-115 is north of the MSD. DW-121 (MF-1) is in the vicinity of Blacktail Creek, south of Silver Bow Creek. Well DW-123 (MF-14) is in Lower Area I in the Montana Pole site area. Well GS-20 is located south of Centennial Street and west of Missoula Gulch. Well DW-123 is on the south side of Silver Bow Creek, and well GS-20 is on the north side of Silver Bow Creek.

3.1.3 Statistical Comparison of Control and Injured Groundwater

The analysis of data was based on all of the repeated measurements (including duplicates and splits) included in the appendices (injured bedrock = App. IIA and IIB, bedrock control = App. IID, injured Area I alluvial = App. IIIA, injured Butte Hill alluvial = App. IIIB, alluvial control = App. IIID). For the bedrock control well analysis, some supplementary summary statistics are provided for the unmineralized, weathered mineralized, and unweathered mineralized portions of the aquifer. For the alluvial analysis, there are two distinct injured areas: Area I and Butte Hill. Data for these two injured alluvial areas are compared to data from baseline alluvial wells using both the descriptive methods and significance testing procedures described below.

In order to collapse the data down to a single number for each well, for each substance, a two-step process was used.

In the first step, any duplicate or split sample data were averaged to provide a single number to summarize the one or more measurements that were made on each well on a given sampling date. In most cases there were no duplicate or split data, so the first stage of collapsing the data had no effect.

In the second step, the single measurements obtained from the first stage of analysis for each sampling data were collapsed further by computing the median of the data over the various sampling dates. In this way, a central value to summarize the data from each well was obtained. This approach, using medians at the second stage of collapsing the data, was used to minimize sensitivity to any outlying values in the repeat data from the well.

The resulting well-by-well values were then used as the basis for subsequent analysis to compare baseline and injured areas. For each substance, using the collapsed well-by-well values, the descriptive comparison of areas is based on use of the median to indicate the central tendency of the data for the area. The spread in the data is indicated by the 25th percentile, the 75th percentile, and the interquartile range, which is the 75th percentile minus the 25th percentile. These descriptive measures were chosen because they are generally applicable and interpretable regardless of the shape of the distribution of the well-by-well data.

A Mann-Whitney nonparametric test of the difference between medians was used to assess whether or not differences observed between the medians for the baseline and injured portions of the aquifer were greater than one could expect by the play of chance in the sampling process. The results of these statistical tests are summarized by two-sided p-values. These calculations were done using the Stata computer software package.

The use of a one-sided testing approach, which would give more significant differences between baseline and injured areas, would actually be justified in this situation because there are only two possible outcomes of interest. Either the presumed injured area has significantly higher median concentrations, or it does not. If the injured area does not have higher median concentrations, the consequences would be the same whether the medians for the injured and baseline wells are the same, or what was presumed to be the injured area actually had a lower median concentration than the baseline area. Thus, from a statistical point of view, it is appropriate to use a one-sided upper alternative hypothesis and the one-sided p-value. However, the more conservative two-sided approach was chosen for the statistical analyses presented.

3.1.3.1 Bedrock Aquifer

Baseline water quality from wells in the bedrock aquifer will be divided into the categories listed below to distinguish the mineralized and unmineralized parts of the bedrock aquifer. For mineralized area, the wells are further split into weathered and unweathered areas. Median concentrations are provided for wells in the unmineralized, weathered mineralized, and unweathered mineralized portions of the aquifer (Table 3-1). However, overall median concentrations for all baseline bedrock groundwater samples are discussed at the end of this section and will be used for comparison to concentration of hazardous substances in injured bedrock groundwater.

Unmineralized Area

BMW-1B	DW-125 (MF-13)	Hall	93-70
BMW-5B	DW-128	Scott	
BMW-11B	DW-129	Tarkelson	
BMW-13B		Johnson	

Mineralized Area

Weathered

Hebgen Park	93-69	93-73	93-83
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Unweathered

A	C	D-2	F
B	D-1	E	

Median concentrations for identified hazardous and related substances in bedrock aquifer baseline groundwater (mineralized and unmineralized) are found in Table 3-1. Median concentrations in the unmineralized, weathered/mineralized, and unweathered/mineralized groundwaters did not exceed any MCL values. However, median concentrations exceeded three SMCL values in the unweathered/mineralized baseline wells: iron, manganese, and sulfate. The median sulfate concentration in the weathered/mineralized wells also exceeded the sulfate SMCL. The unmineralized samples generally had the lowest mean concentrations, while the unweathered/mineralized samples generally had the highest mean concentrations.

As discussed in the previous section, the groundwaters in the central ore zone are considered to be at least somewhat impacted by mining, and also may have naturally-occurring elevated concentrations of several constituents, particularly iron and manganese, which can be elevated under reducing conditions. The elevated iron and manganese concentrations in unweathered bedrock, and to some extent those for sulfate in the weathered/mineralized portion of the

Table 3-1
Median Concentrations of Identified Hazardous Substances in Unmineralized
and Mineralized Portions of the Bedrock Aquifer: Control Wells
($\mu\text{g/l}$; SO_4 in mg/l)

	Unmineralized	Weathered Mineralized	Unweatherized Mineralized
Ag	0.05	1.63	3.48
Al	13	45.3	64.5
As	2.65	2.35	10.9
Be	0.5	ND	1
Cd	0.51	1.6	1.23
Cr	4	2.13	3.01
Cu	15	12	4.25
Fe	13.3	21.4	8,450
Pb	1.05	13.5	1.4
Mn	1	33.5	1,700
Ni	0.65	5.5	14
pH	7.08	6.82	6.54
Sb	10.5	ND	ND
SO_4	166	317	606
Tl	1.0	ND	ND
V	1.5	19	61.5
Zn	18	110	137
Zr	ND	4	29.25

ND = Not Determined.

Source: Appendix IID.

bedrock aquifer, may represent natural background. Elevated concentrations of sulfate (from formation of acid mine drainage under oxidizing conditions) in the mineralized portion of the aquifer are more likely related to mining impacts, such as dewatering and addition of sulfuric acid for underground leaching of copper. The groundwater sampled in the central ore zone (wells A, B, C, D-1, D-2, E, F, 93-83) has acquired sulfate along its flow path from traveling through the oxidized portions of the mineralized zone, which have been increased in extent as a result of dewatering activities. Apparently the acquired sulfate is not currently being reduced within the unweathered mineralized portion of the bedrock aquifer in Butte Hill.

Baseline bedrock groundwater quality will be represented by median concentration values [43 CFR § 11.72 (h)(5)]. Overall median values and percentiles for all baseline bedrock groundwater samples are presented in Table 3-2A. The wells have been combined to represent overall baseline quality of the aquifer as a whole, including the wells that may be somewhat impacted by mining in the central ore zone. No median concentration exceeds either an MCL or SMCL value.

The medians, percentiles, and interquartile ranges for the injured bedrock wells are presented in Table 3-2B. The MCL value for cadmium (5µg/l) was exceeded, and SMCL values for iron, manganese, pH, zinc, and sulfate were also exceeded.

Table 3-2A
Median Concentrations, Percentiles, and Interquartile Ranges
of Substances in Bedrock Control Wells
(µg/l; SO₄ in mg/l)

Analyte	# Wells	Median Concentration	25% Percentile	75% Percentile	Interquartile Range
Ag	14	1.96	0.5	3.48	2.98
Al	15	24.5	15	74	59
As	22	3.13	2	10.5	8.5
Be	9	1	0.5	1	0.5
Cd	22	1.02	0.51	1.75	1.24
Cr	15	3.01	1.75	4	2.25
Cu	22	8.5	2	18	16
Fe	23	40	2.5	1,100	1,097.5
Mn	19	45.1	1	1,560	1,559
Ni	14	6.9	1.0	19	18.0
pH	23	7.06	6.79	7.8	1.01
Sb	3	10.5	10.5	10.5	0
SO ₄	32	174	52.5	332	279.5
Tl	3	1	1	1	0
V	8	38	3.1	61.5	58.4
Zn	22	80.5	18	438	420
Zr	5	22	21	36.5	15.5

Source: Appendix IID.

Table 3-2B
Median Concentrations, Percentiles, and Interquartile Ranges
of Substances in Injured Bedrock Wells
 (µg/l; SO₄ in mg/l)

Analyte	# Wells	Median Concentration	25% Percentile	75% Percentile	Interquartile Range
Ag	6	30.65	15.85	32.65	16.8
Al	11	20	15	1,280	1,265
As	11	28.6	12	153	141
Cd	11	9.5	1	120	119
Cr	11	2.5	1	2.6	1.6
Cu	11	25	6.5	590	583.5
Fe	11	4,640	409	24,700	24,291
Mn	11	2,400	1,250	6,870	5,620
Ni	6	356	122.8	599.5	476.7
pH	11	6.1	5.73	6.6	0.87
SO ₄	11	948	627	2,050	1,423
Zn	11	16,200	36	93,700	93,664

Sources: Appendices IIA and IIB.

P-values for the comparison of median concentrations in baseline and injured bedrock groundwater are presented in Table 3-3. All substances of concern except for aluminum and chromium show a statistically significant difference (at a p-value of 0.05) between injured and baseline bedrock groundwater. In order to establish that differences between the control and injured areas are statistically significant, the median concentrations should be compared using the Mann-Whitney test [43 CFR § 11.72 (h)(5)]. All substances of concern with median concentrations that exceeded relevant standards in injured bedrock groundwater had statistically significant p-values when compared to median concentrations of these substances in baseline or control bedrock groundwater, which indicates that there is a statistically significant difference between baseline and injured bedrock groundwater.

Table 3-3
Bedrock Aquifer
Comparison of Baseline and Injured Areas: Median Concentrations ($\mu\text{g/l}$; SO_4 in mg/l)
and Two-Sided p-Values

Analyte	Baseline	Injured	p-Value
Ag	1.96	30.65	0.0005
Al	24.5	20	0.4675
As	3.13	28.6	0.0016
Cd	1.02	9.5	0.0017
Cr	3.01	2.5	0.1611
Cu	8.5	25	0.0374
Fe	40	4,640	0.0019
Mn	45.1	2,400	0.0016
Ni	6.9	356	0.0005
pH	7.06	6.1	0.0002
SO_4	174	948	0.0001
Zn	80.5	16,200	0.0026

Source: Appendix II.

3.1.3.2 Alluvial Aquifer

Baseline range and median concentrations of hazardous substances in alluvial aquifer groundwaters in the study area are shown in Tables 3-4A through C. Median concentrations will be used to represent baseline conditions (Table 3-4A). One of three samples from well GS-20 exceeds the thallium MCL; however, the other two samples for this well taken within one year of the first sample do not show that the thallium MCL value ($2 \mu\text{g/l}$) was exceeded. The antimony MCL ($6 \mu\text{g/l}$) was actually not exceeded in any well. All values were below detection ($21 \mu\text{g/l}$), and one-half that value was used in the statistical analyses. Median concentrations for the alluvial control well samples (Table 3-4A) show no other MCL or SMCL exceedences in the baseline alluvial groundwater.

Table 3-4A
Median Concentrations, Percentiles, and Interquartile Ranges
of Substances in Alluvial Aquifer Control Wells
($\mu\text{g/l}$; SO_4 in mg/l)

Analyte	# Wells	Median Concentration	25% Percentile	75% Percentile	Interquartile Range
Al	5	9.4	7.8	11.5	3.7
As	9	1.6	1.5	1.75	.25
Cd	9	.55	.5	1.4	.9
Cr	6	3.45	1.6	4	2.4
Cu	9	3.75	3.1	13.5	10.4
Fe	9	54	16.5	116	99.5
Mn	6	33	20	69	49
Ni	6	1.58	1	1.9	0.9
Ag	5	0.5	.1	.5	.4
Zn	9	85	47	188	141
SO_4	7	149	59	199	140
Be	5	.5	.5	.5	0
Tl	2	2.75	1	4.5	3.5
Sb	2	10.5	10.5	10.5	0

Source: Appendix IIID.

Median concentrations for substances in the injured Area I and Butte Hill alluvial aquifers are shown in Tables 3-4B and 3-4C, respectively. Median concentrations exceeded MCL values for cadmium, and thallium and SMCL values for manganese, zinc, and sulfate in the Area I wells (Table 3-4B). Median concentrations exceeded MCL values for cadmium and SMCL values for copper, manganese, zinc, sulfate, and TDS in the Butte Hill wells (Table 3-4C).

Table 3-4B
Median Concentrations, Percentiles, and Interquartile Ranges
of Substances in Injured Area I Alluvial Aquifer Wells
(µg/l; SO₄ in mg/l)

Analyte	# Wells	Median Concentration	25% Percentile	75% Percentile	Interquartile Range
Al	83	157	11	660	649
As	83	4.4	1.5	19	17.5
Cd	83	23.8	3	210	207
Cr	83	4	4	4	0
Cu	83	90.5	6.85	5,000	4,993.15
Fe	83	98	10.5	13,600	13,589.5
Mn	83	11,000	140	37,800	37,660
Ni	83	8.9	1.6	81.6	80
Zn	83	7,200	430	52,000	51,570
SO ₄	84	541	300	1,510	1,210
Be	83	0.5	0.5	1.5	1.0
Co	83	8.1	4	65.8	61.8
Tl	83	5	2	20	18

Source: Appendix IIIA.

Table 3-5 shows p-values for the Area I and Butte Hill wells as compared to baseline alluvial aquifer wells. All p-values for the Area I/baseline comparison show a statistically significant difference between baseline and injured groundwater, except for iron. All substances that have median values exceeding relevant standards do have significant p-values when baseline and injured concentrations are compared. For the Butte Hill/baseline comparison, arsenic, chromium, iron, and manganese do not have statistically significant p-values. This may reflect the differences in concentrations in the shallower and deeper wells. For substances that do exceed relevant standards, only manganese does not show a statistically significant difference between baseline and injured wells when compared using the Mann-Whitney test.

Table 3-4C
Median Concentrations, Percentiles, and Interquartile Ranges
of Substances in Injured Butte Hill Alluvial Aquifer Wells
 (µg/l, unless otherwise noted)

Analyte	# Wells	Median Concentration	25% Percentile	75% Percentile	Interquartile Range
Al	15	210	17.4	63,200	63,182.6
As	15	0.95	0.5	2.75	2.25
Cd	15	44.1	5.9	3,820	3,814.1
Cr	15	2	1.8	5.95	4.15
Cu	15	1,080	233	74,400	74,167
Fe	15	39.5	13.6	156	142.4
Mn	15	166	10.8	167,000	166,989.2
Ni	15	57.4	7	2,140	2,133
Ag	15	1	0.5	22.7	22.2
Zn	15	8,520	1,190	379,000	377,810
F (mg/l)	15	1.0	0.45	25.2	24.75
SO ₄ (mg/l)	15	810	463	5,160	4,697
TDS (mg/l)	15	1,310	895	7,120	6,225

Source: Appendix IIIB.

3.1.4 Comparison to Concentrations in Uncontaminated Groundwaters Cited in the Literature

Table 3-6 presents major ion chemistry of groundwater or springs in primarily igneous rock areas (Freeze and Cherry, 1979). These waters are generally of low ionic strength and have low sulfate concentrations. Tables 3-5 and 3-6 present water chemistry from groundwaters, springs, hot springs and surface waters that are high in dissolved aluminum or manganese, and iron, respectively (Hem, 1992). Analyses 1 and 4 in Table 3-7 represent water of low pH, which can be responsible for generating high concentrations of dissolved aluminum (Hem, 1992). Analyses 1, 2 and 3 in Table 3-8 probably typify iron-containing groundwater where a pyrite-oxidation mechanism is plausible (Hem, 1992). These analyses do show that

Table 3-5
Alluvial Aquifer
Comparison of Baseline and Injured Areas: Median Concentrations and p-Values
($\mu\text{g/l}$; SO_4 in mg/l)

Analyte	Baseline	Area I		Butte Hill	
	Median	Median	p-Value	Median	p-Value
Al	9.4	157	0.0070	210	0.0164
As	1.6	4.4	0.0457	.95	0.4929
Cd	.55	23.8	0.0002	44.1	0.0003
Cr	3.45	4	0.0255	2	0.9379
Cu	3.75	90.5	0.0079	1,080	0.0002
Fe	54	98	0.3750	39.5	0.9287
Mn	33	11,000	0.0016	166	0.4835
Ni	1.58	8.9	0.0189	57.4	0.0005
Ag	0.5	ND	ND	1	0.0060
Zn	85	7,200	0.0002	8,520	0.0002
SO_4	149	541	0.0006	810	0.0007
Be	.5	0.5	NC	ND	ND
* not computed NC not calculated ND Not determined Source: Appendix III.					

naturally elevated concentrations of sulfate, iron, aluminum and manganese can occur in groundwaters under certain geochemical conditions; however, none of these waters is quite comparable to groundwater in the study area.

Table 3-9 presents ranges of pH values and concentrations of copper, zinc, lead and cadmium in shallow groundwaters and springs (some compilations of samples include surface water samples) in contact with undisturbed mineral deposits (Runnells et al., 1992). Maximum values for copper exceeded 1000 $\mu\text{g/l}$ in three of 12 sites reporting data (all springs); zinc concentrations exceeded 5000 $\mu\text{g/l}$ at only one site; lead values exceeded 50 $\mu\text{g/l}$ in 5 of 7 sites reporting data for springs and groundwaters, and cadmium concentrations exceeded

Table 3-6
Mean Values or Major-Ion Composition of Groundwater and Groundwater-Derived
Surface Water in Primarily Igneous Rock Areas (mg/l)

Location*	Number	pH	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻	SiO ₂	Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺
(1) Vosges, France	51	6.1	15.9	3.4	10.9	11.5	3.3	1.2	5.8	2.4
(2) Brittany, France	7	6.5	13.4	16.2	3.9	15.0	13.3	1.3	4.4	2.6
(3) Central Massif, France	10	7.7	12.2	2.6	3.7	15.1	4.2	1.2	4.6	1.3
(4) Alrance Spring F, France	77	5.9	6.9	<3	1.15	5.9	2.3	0.6	1.0	0.4
(5) Alrance Spring A, France	47	6.0	8.1	<3	1.1	11.5	2.6	0.6	0.7	0.3
(6) Corsica	25	6.7	40.3	22.0	8.6	13.2	16.5	1.4	8.1	4.0
(7) Senegal	7	7.1	43.9	4.2	0.8	46.2	8.4	2.2	8.3	3.7
(8) Chad	2	7.9	54.4	<3	1.4	85	15.7	3.4	8.0	2.5
(9) Ivory Coast (Korhogo, dry season)	54	5.5	6.1	<3	0.4	10.8	0.8	1.0	1.0	0.10
(10) Ivory Coast (Korhogo, wet season)	59	5.5	6.1	<3	0.5	8.0	0.2	0.6	<1	<0.1
(11) Malagasy (high plateaus)	2	5.7	6.1	1	0.7	10.6	0.95	0.62	0.40	0.12
(12) Sierra Nevada, Calif. (ephemeral springs)		6.2	2.0	0.5	1.0	16.4	3.03	1.09	3.11	0.70
(13) Sierra Nevada, Calif. (perennial springs)		6.8	54.6	1.06	2.38	24.6	5.95	1.57	10.4	1.70
(14) Kenora, NW Ontario (unconfined aquifer)	12	6.3	24.0	0.6	1.1	18.7	2.07	0.59	4.8	1.54
(15) Kenora, NW Ontario (confined aquifer)	6	6.9	59.2	0.7	0.8	22.1	3.04	1.05	11.9	4.94

* (1), A spring after thawing, 1967; (2) and (3), streams after several dry months, summer 1967; (4) and (5), two springs throughout 1966; (6), streams throughout the Island after 6 dry months, 1967; (7), streams in eastern regions, dry season 1967; (8), stream in Guera, dry season 1967; (9) and (10), streams in Korhogo area, 1965; (11), on the high plateaus and on the eastern coast, dry season 1967; (12) and (13), springs during 1961; (14) and (15), piezometers in glacial sands derived from granitic Precambrian rocks.

SOURCES: Tardy, 1971 (1) to (11); Feth et al., 1964 (12) and (13); and Bottomley, 1974 (14) and (15).

Source: Freeze and Cherry, 1979.

Table 3-7
Analyses of Waters High in Dissolved Aluminum and Manganese

Constituent	1		2		3		4		5	
	Dec. 13, 1955		Dec. 3, 1955		Aug. 31, 1958		Mar. 1-6, 8-10, 1963		Mar. 25, 1953	
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
Silica (SiO ₂)	98		10		92		9.7		31	
Aluminum (Al)	28		.1		.35		3.5		.2	
Iron (Fe)	.88		.04		.02		.10		2.7	
Manganese (Mn)	9.6		1.3		.31		2.5		.22	
Calcium (Ca)	424	21.16	58	2.89	67	3.34	32	1.60	28	1.40
Magnesium (Mg)	194	15.96	13	1.07	.0	.00	11	.90	1.9	.16
Sodium (Na)	416	18.10	23	1.00	477	20.75	12	.52	6.8	.30
Potassium (K)	11	.28	2.8	.07	40	1.02	3.7	.09	4.2	.11
Hydrogen (H)		.10						.16		
Carbonate (CO ₃)	0		0		0	.00	0			
Bicarbonate (HCO ₃)	0		101	1.66	1,020	16.72	0		121	1.98
Sulfate (SO ₄)	2,420	50.38	116	2.42	169	3.52	171	3.56	1.4	.03
Chloride (Cl)	380	10.72	39	1.10	206	5.81	5.0	.14	1.0	.03
Fluoride (F)	1.8	.09	.0		6.8	.36	.1	.01	.1	.01
Nitrate (NO ₃)	3.1	.05	.6	.01	1.8	.03	5.3	.09	.2	.00
Orthophosphate (PO ₄)	.0		.1		.11				.0	
Boron (B)					2.8					
Dissolved solids:										
Calculated	3,990		314		1,570		256		137	
Residue at 180°C	4,190		338		1,560		260			
Hardness as CaCO ₃	1,860		198		168		125		78	
Noncarbonate	1,860		115		0		125		0	
Specific conductance (micromhos at 25°C)	4,570		517		2,430		507		192	
pH	4.0		7.0		6.7		3.8		6.9	

1. Well, 7 mi northeast of Monticello, Drew County, Ark. Depth, 22 ft. Water-bearing formation, shale, sand, and marl of the Jackson Group. Also contained radium (Ra), 1.7 pCi/L, and uranium (U), 17 µg/L.
2. Composite from two radial collector wells at Parkersburg, Kanawha County, W. Va. Depth, 52 ft. Water from sand and gravel. Also contained copper (Cu), 0.01 mg/L, and zinc (Zn), 0.01 mg/L.
3. Wagon Wheel Gap hot spring, Mineral County, Colo. Discharge, 20 gpm; temperature, 62.2°C. Associated with vein of the Wagon Wheel Gap fluorite mine. Also contained 2.3 mg/L Li, 0.9 mg/L NH₄, 0.3 mg/L Br, and 0.3 mg/L I.
4. Kiskiminitas River at Leechburg (Vandergrift), Pa. Composite of nine daily samples. Mean discharge for period, 10,880 cfs.
5. Well, 167 ft deep, Baltimore County, Md. Water-bearing formation, Port Deposit granitic gneiss. Also contained 0.01 mg/L copper (Cu).

Source: Hem, 1992.

Table 3-8
Analyses of Waters Containing Iron

Constituent	1		2		3		4	
	May 28, 1952		Mar. 8, 1952		Feb. 27, 1952		Oct. 1-31, 1962	
	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L	mg/L	meq/L
Silica (SiO ₂)	20		12		26		11	
Aluminum (Al)			1.2		1.2			
Iron (Fe)	2.3		2.9		10		1.4	
Manganese (Mn) .....	.00							
Calcium (Ca)	126	6.29	2.7	.135	8.8	.439	18	.898
Magnesium (Mg)	43	3.54	2.0	.164	8.4	.691	8.0	.658
Sodium (Na)	13	.56	35	1.522	34	1.478	} 9.3	.40
Potassium (K)	2.1	.05	1.7	.044	2.9	.074		
Bicarbonate (HCO ₃)	440	7.21	100	1.639	65	1.065	69	1.131
Sulfate (SO ₄)	139	2.89	5.6	.117	71	1.478	29	.604
Chloride (Cl)	8.0	.23	2.0	.056	2.0	.056	6.4	.181
Fluoride (F) .....	.7	.04	.1	.005	.3	.016		
Nitrate (NO ₃) .....	.2	.00	.6	.010	.0	.000	2.9	.046
Dissolved solids:								
Calculated	594		113		187			
Residue on evaporation	571		101		180		156	
Hardness as CaCO ₃	490		15		56		78	
Noncarbonate	131		0		3		21	
Specific conductance	885		162		264		188	
(micromhos at 25°C).								
pH	7.6		7.4		6.4		6.9	
Color	1		23		7		140	
Acidity as H ₂ SO ₄ (total)								

1. Well 3, Nelson Rd., Water Works, Columbus, Ohio. Depth, 117 ft; temperature, 13.3°C. Water from glacial outwash.
2. Well 79-8-50, public supply, Memphis, Tenn. Depth, 1,310 ft; temperature, 22.2°C. Water from sand of the Wilcox Formation.
3. Well 5:290-1, 6 mi southeast of Maryville, Blount County, Tenn. Depth, 66 ft; temperature, 14.4°C. Water from the Chattanooga Shale.
4. Partridge River near Aurora, Minn. Composite sample. Mean discharge, 30.8 cfs.
5. Brine produced with oil from well in NW 1/4 sec. 3, T. 11 N., R. 12 E., Okmulgee County, Okla. Depth, 2,394 ft. Water from the Gilcrease sand of drillers, Atoka Formation.

Source: Hem, 1992.

Table 3-9
Ranges of Compositions of Surface and Shallow Groundwaters in Contact with Undisturbed Mineral Deposits

Location (Type of Water Sampled)	Rocks	pH	Concentration (mg/L)			
			Cu	Zn	Pb	Cd
North Wales, Great Britain (stream and groundwater)	Turbidite, slate, diorite	nr	> 0.10 ^b	nr	nr	nr
Russia (six regions) (groundwater)	nr	nr	0.01-0.13	0.04-0.5	nr	nr
Northwest Territories, Canada (2 springs)	Metavolcanics, carbonate-poor	3.4	0.87-2.1	1.1-2.0	0.34-0.51	nr
Russia (many sites; maximum values in shallow groundwaters)	Shallow portions of weathered ore deposits	6.2-7.8	1.0 (max.)	2.5 (max.)	0.25 (max.)	0.26 (max.)
Arkansas, Ouachita Mtns. (regional groundwater)	Shale, chert, sandstone, limestone	nr	0.001-0.85	0.002-0.14	< 0.01-0.059	nr
Northwest Arizona (one spring)	Intrusive igneous	4.0	12.0 ^b	3.3 ^b	nr	nr
Czechoslovakia (many springs, wells, streams)	nr	nr	nr	0.05-0.25 (Zn or Pb, not specified)	nr	nr
Wisconsin Zn-Pb district (3,766 springs)	Dolomite, chert, limestone	6.9-7.4 (21 samples)	nr	0.05-0.27 (75th percentile, mainly Zn)	nr	nr
Wisconsin (approx. 90 springs and streams)	Dolomite, chert, limestone	7.1-8.7	nr	< 0.002-1.5 (total heavy metals, mainly Zn)	nr	nr
Ontario, Canada (four shallow groundwaters)	Precambrian metamorphics	nr	0.003-0.070	nr	nr	nr
Park County, Montana (two springs)	Igneous, sedimentary, contact	2.73-3.93	0.30-7.9	0.07-1.1	< 0.01	< 0.0002-0.003
Basin and Parent Creeks, Yukon (three springs)	Metamorphic, with minor limestone	4-6	0.080, 1.7, 50. (total heavy metals, mainly Zn)			
Flambeau, Wisconsin (groundwater)	Precambrian volcanics	5.8-7.4	0.003-0.085 ^b	0.005-1.8 ^b	< 0.0025 ^b	0.0002-0.024 ^b
Crandon, Wisconsin (groundwater)	Glacial drift, above subcrop of sulfide ore in volcanics	7.7 (mean)	< 0.001-0.09 ^b	< 0.001-2.6 ^b	< 0.01-0.10 ^b	< 0.001-0.015 ^b
Crandon, Wisconsin (groundwater)	Volcanic bedrock (six deep drillholes)	5.9-8.1	< 0.001-0.27 ^b	0.041-1.5 ^b	< 0.01-0.39 ^b	< 0.001-0.027 ^b

^a Type of enclosing rock is listed if reported. Values are for total metal except where indicated; nr = not reported; max. = maximum value reported; na = not applicable, Runnells, D. D. University of Colorado, Boulder, unpublished data, 1981.

^b Dissolved = Filtered value.
Source: Runnells et al., 1992.

5 µg/l at 4 of 5 sites with data for springs or groundwater. The quality of these data is not established in the article, although it can be assumed that few if any of the samples were collected and analyzed using U.S. EPA protocols. These analyses do show that naturally elevated concentrations of some metals can exist in groundwaters in the vicinity of mineral deposits. However, none of the areas described by the authors are documented as being similar in geologic or hydrologic setting to the Butte area; therefore, the data are not directly relevant to conditions in the study area.

3.2 EXTENT OF INJURED GROUNDWATER

3.2.1 Areal Extent of Injured Groundwater

3.2.1.1 Bedrock Aquifer

A significant portion of injured water associated with the bedrock aquifer is in the Berkeley Pit. Water quality data for historic and recent sampling of pit water are presented in Appendix I. Concentrations of hazardous substances in Berkeley Pit water exceeded primary and/or secondary drinking water standards for pH, sulfate, TDS, fluoride, iron, manganese, aluminum, silver, arsenic, cadmium, copper, nickel, lead and zinc. Cobalt, molybdenum, vanadium and zirconium concentrations were also elevated. Concentrations are plotted versus depth for Berkeley Pit waters in Figures 3-7A through 3-7I. Relevant MCL and SMCL values are also plotted for comparison of pit water concentrations to drinking water standards.

Butte Hill bedrock groundwater quality data are presented in Appendix II. The areal extent of injury is approximately the same for both hazardous and other (e.g., sulfate) substances of concern.

The areal extent of injured bedrock groundwater in the Butte Hill area is based on subsurface mine map information presented in Table 3-10. A polygon was constructed to include the farthest extent of mining projected to the surface. The total area of the East Camp system is approximately 1.66×10^8 square feet; the area of the West Camp is approximately 1.43×10^7 square feet, and the Outer Camp is 1.66×10^6 square feet. The areal extent of injured bedrock aquifer groundwater in the Butte Hill area is 1.8×10^8 square feet (6.46 square miles or 4,133 acres). The areal extent of injured groundwater in the Berkeley Pit is 2.126×10^7 square feet (0.76 square miles or 488 acres). The total areal extent of injured bedrock groundwater in the Butte Hill area is 2.01×10^8 square feet (7.22 square miles or 4,620 acres). The approximate areal extent of injury is shown on Figure 3-8 and encompasses the area of connected underground mine workings. Those wells used for baseline groundwater quality are not part of the connected mine workings, but are within the injured area. Figure 3-8, taken from the Record of Decision (U.S. EPA, 1994), shows a somewhat larger area of extent than that calculated above.

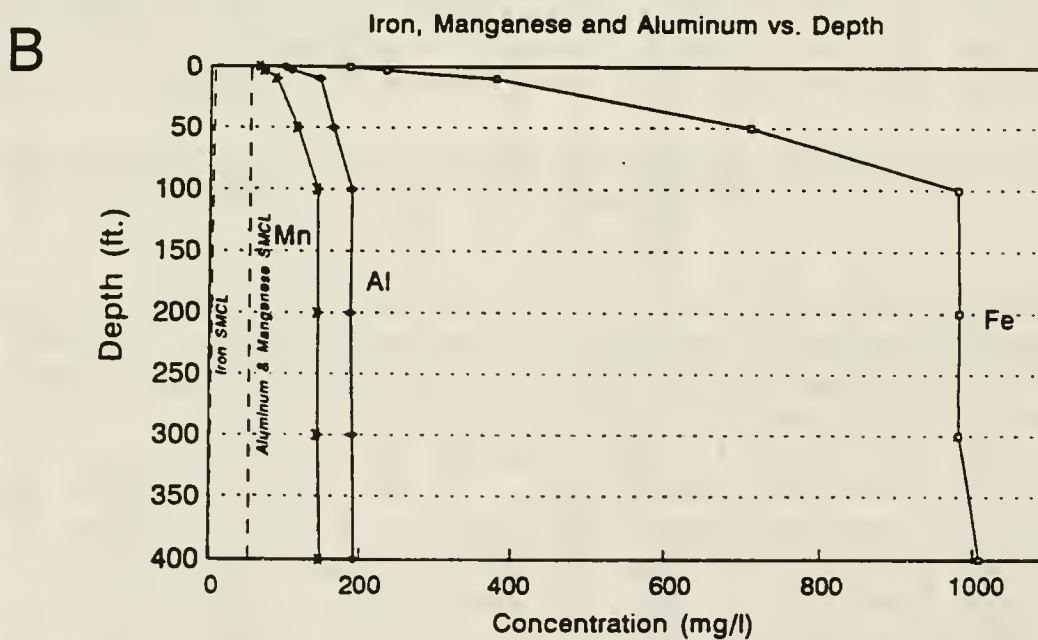
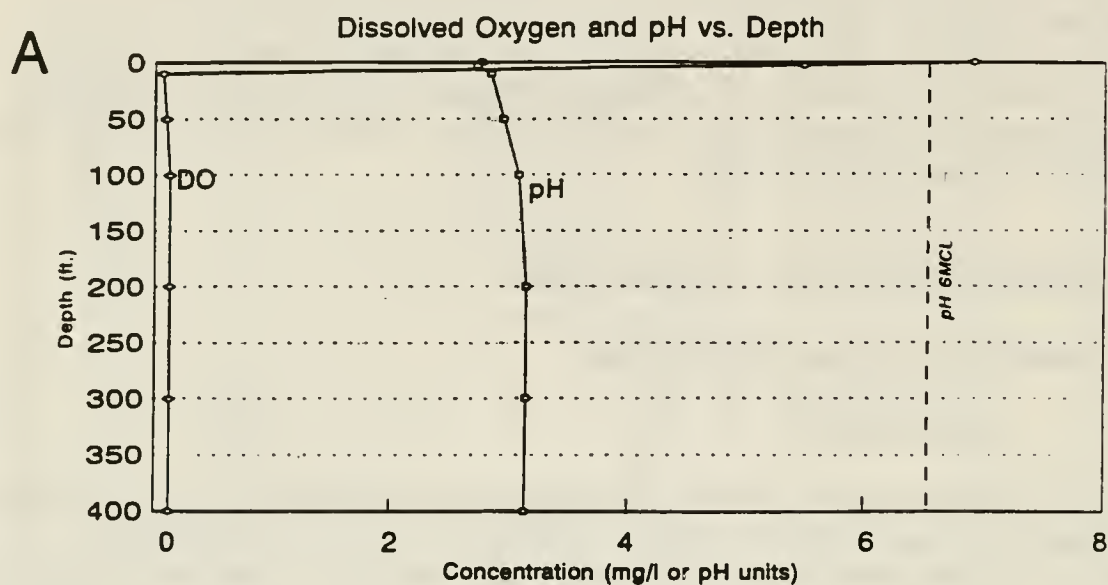


Figure 3-7A & 3-7B.

Berkeley Pit Water Chemistry, Concentrations vs. Depth for:
 (A) Dissolved Oxygen and pH; (B) Iron, Manganese and
 Aluminum. Source: Appendix I.

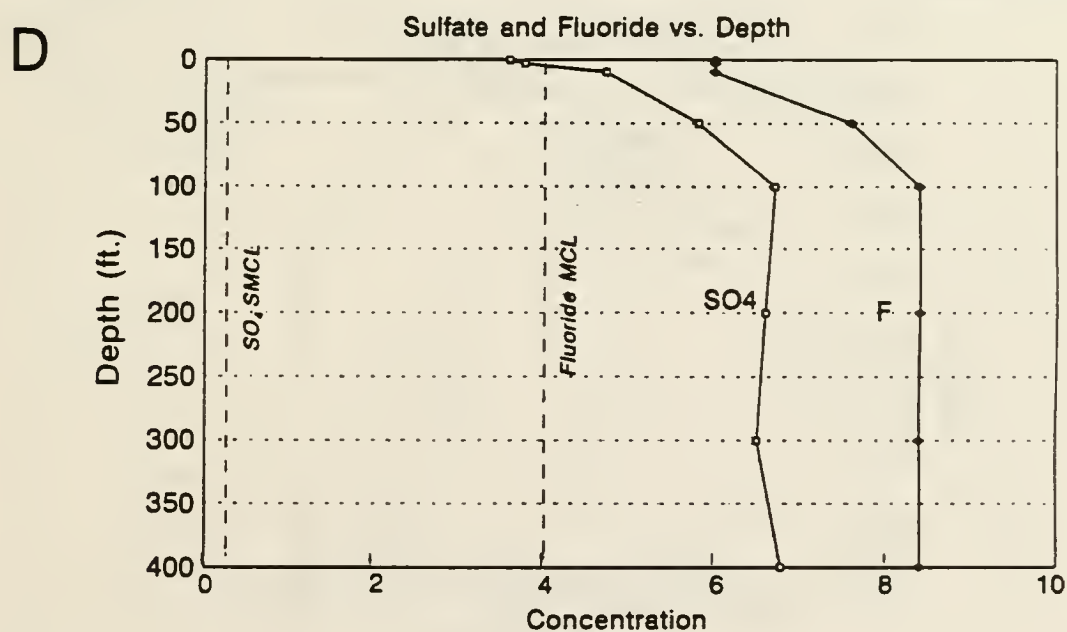
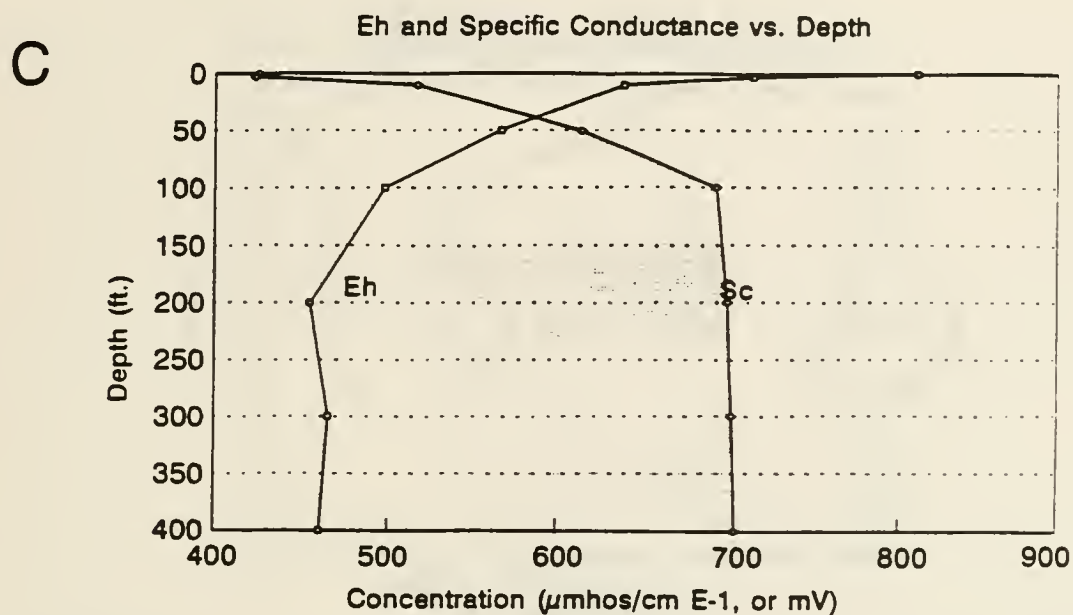
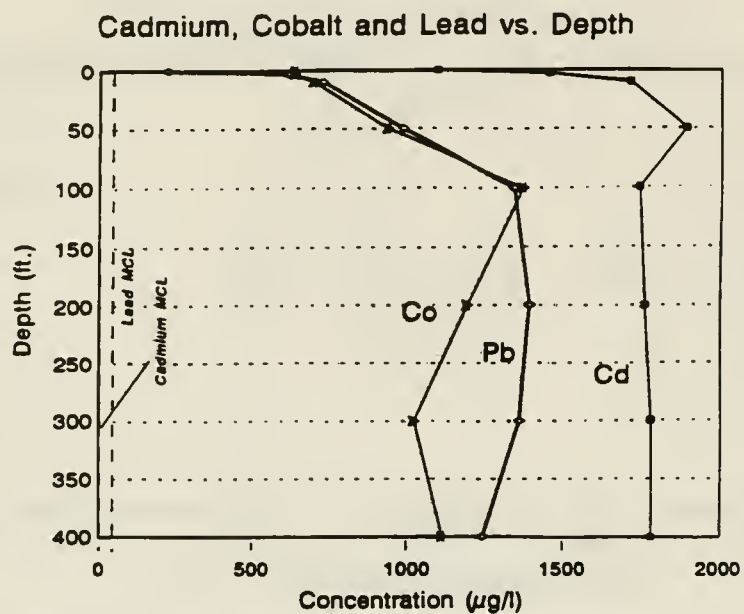


Figure 3-7C & 3-7D.

Berkeley Pit Water Chemistry, Concentrations vs. Depth for (C) Eh and Specific Conductance; and (D) Sulfate and Fluoride. Source: Appendix I.

E



F

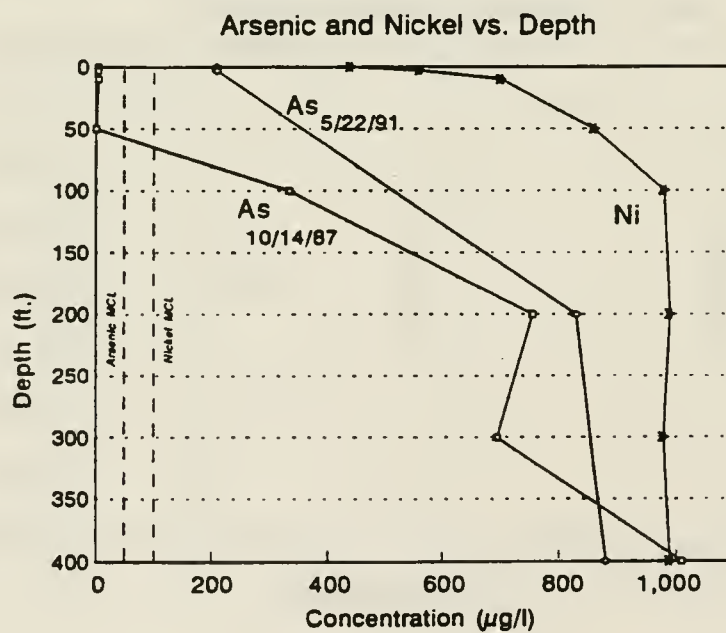


Figure 3-7E & 3-7F.

Berkeley Pit Water Chemistry, Concentrations vs. Depth for:
 (E) Cadmium, Cobalt and Lead; (F) Arsenic and Nickel.
 Source: Appendix I.

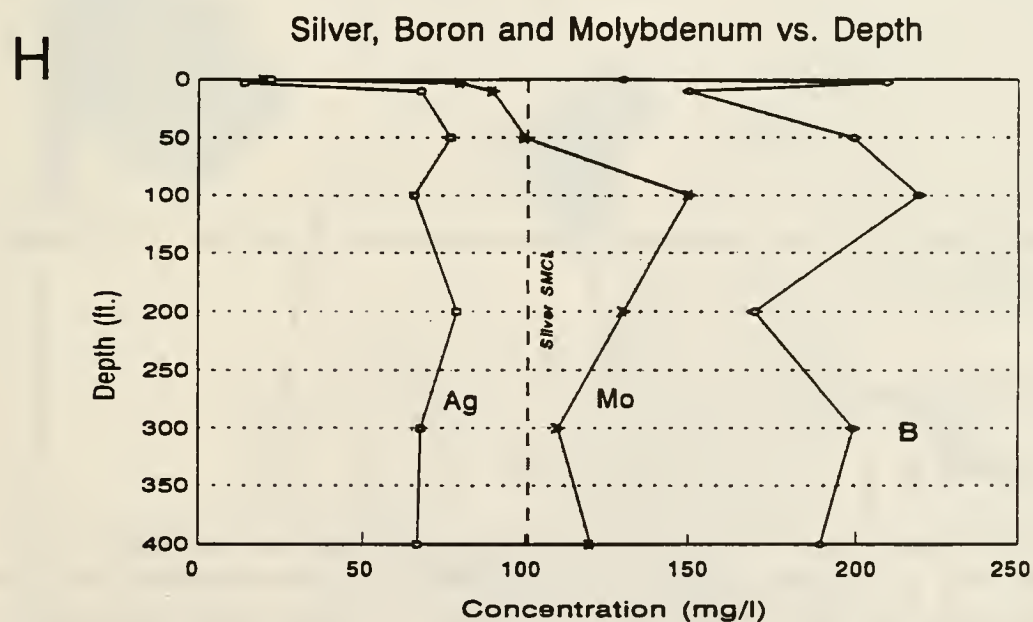
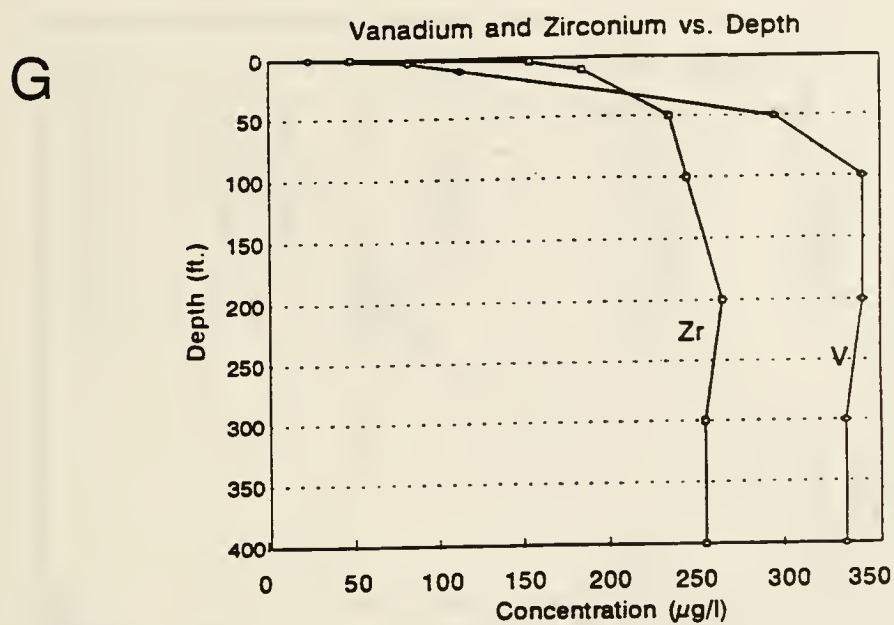


Figure 3-7G & 3-7H.

Berkeley Pit Water Chemistry, Concentrations vs. Depth for:
(G) Vanadium and Zirconium; (H) Silver, Boron and
Molybdenum. Source: Appendix I.

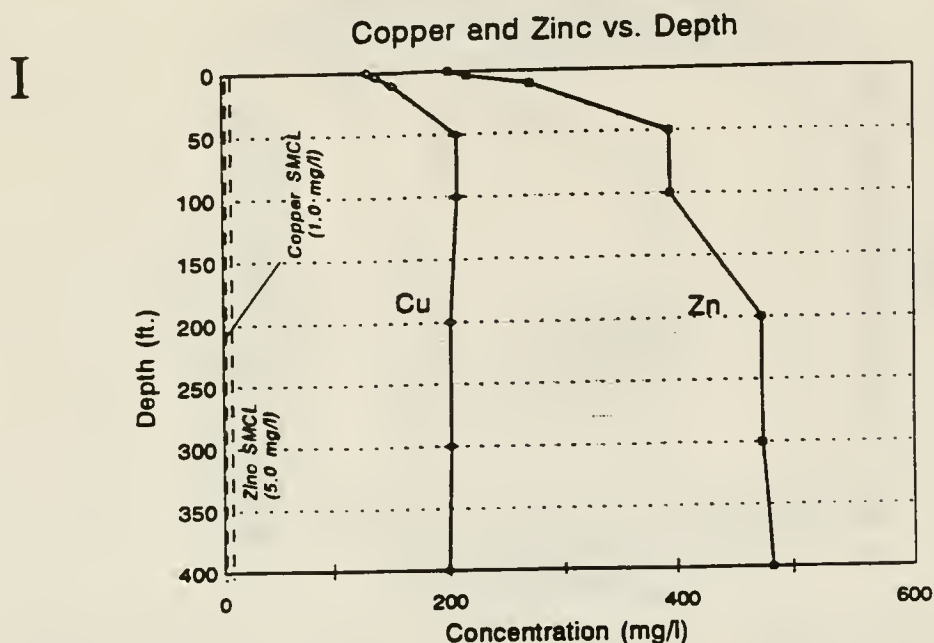


Figure 3-7I. Berkeley Pit Water Chemistry, Concentrations vs. Depth for: (I) Copper and Zinc. Source: Appendix I.

3.2.1.2 Alluvial Aquifer

3.2.1.2.1 Butte Hill

The areal extent of injured alluvial groundwater in the Butte Hill area was estimated using isopleth maps for iron, zinc, sulfate, cadmium, arsenic, lead and copper constructed using data in Appendix III plotted with the graphing program SURFER.¹ The areal extent of injured groundwater for each constituent (area exceeding MCL or SMCL values) was estimated using the 2-D contour plots like those shown in Figures 3-9A through 3-9C for cadmium, copper, and sulfate. The x and y axes on these figures are longitude and latitude. The area

¹ The location of the wells can be found in Figure 2-4 and Plate I.

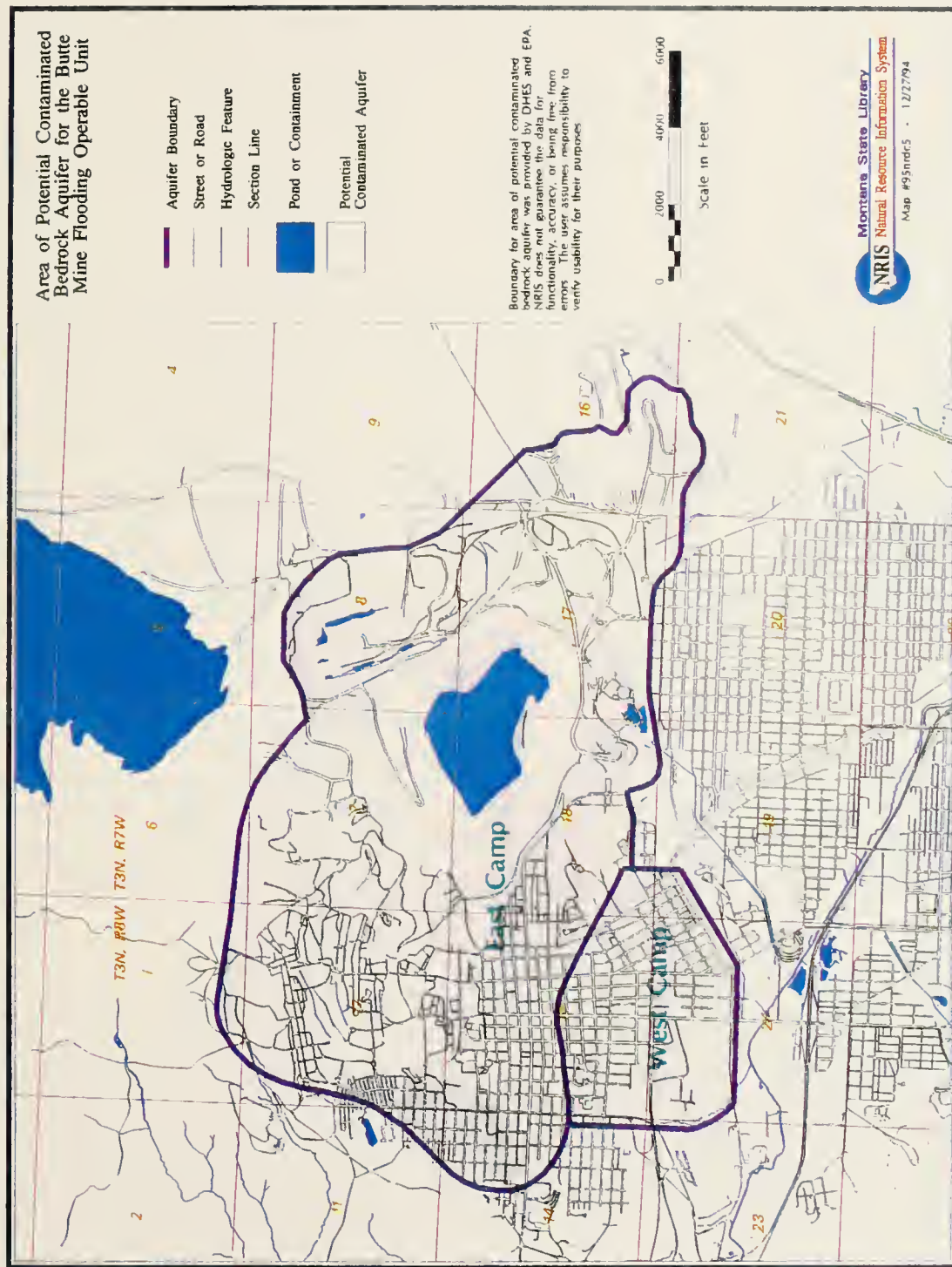


Figure 3-8. Area of Potential Contaminated Bedrock Aquifer in the Butte Hill Area. Source: U.S. EPA, 1994.

Table 3-10
Mine Projection Map Information Used to Calculate Area and Volume of Injured Bedrock
Groundwater in the Butte Hill Area

Sheet Number	Area (sq ft)	Range (level)	Thickness (feet)	Volume (cu ft)
4	25,217,920	400 to 800	500	1.26E+10
9	86,158,720	900 to 1,300	500	4.31E+10
14	133,514,880	1,400 to 1,800	500	6.68E+10
19	136,224,960	1,900 to 2,000	200	2.72E+10
21	163,393,760	2,100 to 2,500	500	8.17E+10
26	95,477,280	2,600 to 3,000	500	4.77E+10
31	139,961,120	3,100 to 4,000	1,000	1.40E+11
41	90,702,560	4,100 to 4,500	500	4.54E+10
46	23,477,600	4,600 to 5,000	500	1.17E+10
51	4,664,640	5,100 to 5,200	100	4.66E+08

Notes:

1. Elevation of Base of Pit = 4,320 ft. (AMC); 4,263 ft. (USGS).
2. Base of Pit corresponds to the 1,600 level of the Kelley Mine.
3. The 1,600 level of the Kelley Mine corresponds to Sheet 21.
4. The Kelley Pump Station is on the 3,900 level.
5. Present elevation of water level in Pit = 5,040 ft. (USGS).
6. An elevation of 5,040 ft. corresponds to the 800 level of the Kelley Mine (Sheet 14).
7. Current action level elevation (5,410 ft. USGS) corresponds to the 450 level of the Kelley Mine (Sheet 9).

exceeding the MCL or SMCL value was estimated using a planimeter. Zinc, copper, iron, lead, cadmium, and sulfate concentrations exceeded relevant water quality standards. The water quality standard for zinc was exceeded in every well; the water quality standard for lead was exceeded in only two wells. Sulfate concentrations exceeded the SMCL value (250 mg/l) in all but one well (LP10). The information used to calculate the area of injured alluvial groundwater in the Butte Hill area is presented in Table 3-11, and the areal extent of each contaminant plume is presented in Table 3-12. The areal extent of injured groundwater in the Butte Hill alluvial aquifer is given by the extent of the zinc plume (the zinc SMCL was exceeded in all wells), which is 2.20×10^7 ft² (0.79 mi² or 505 acres), as shown in Table 3-12.

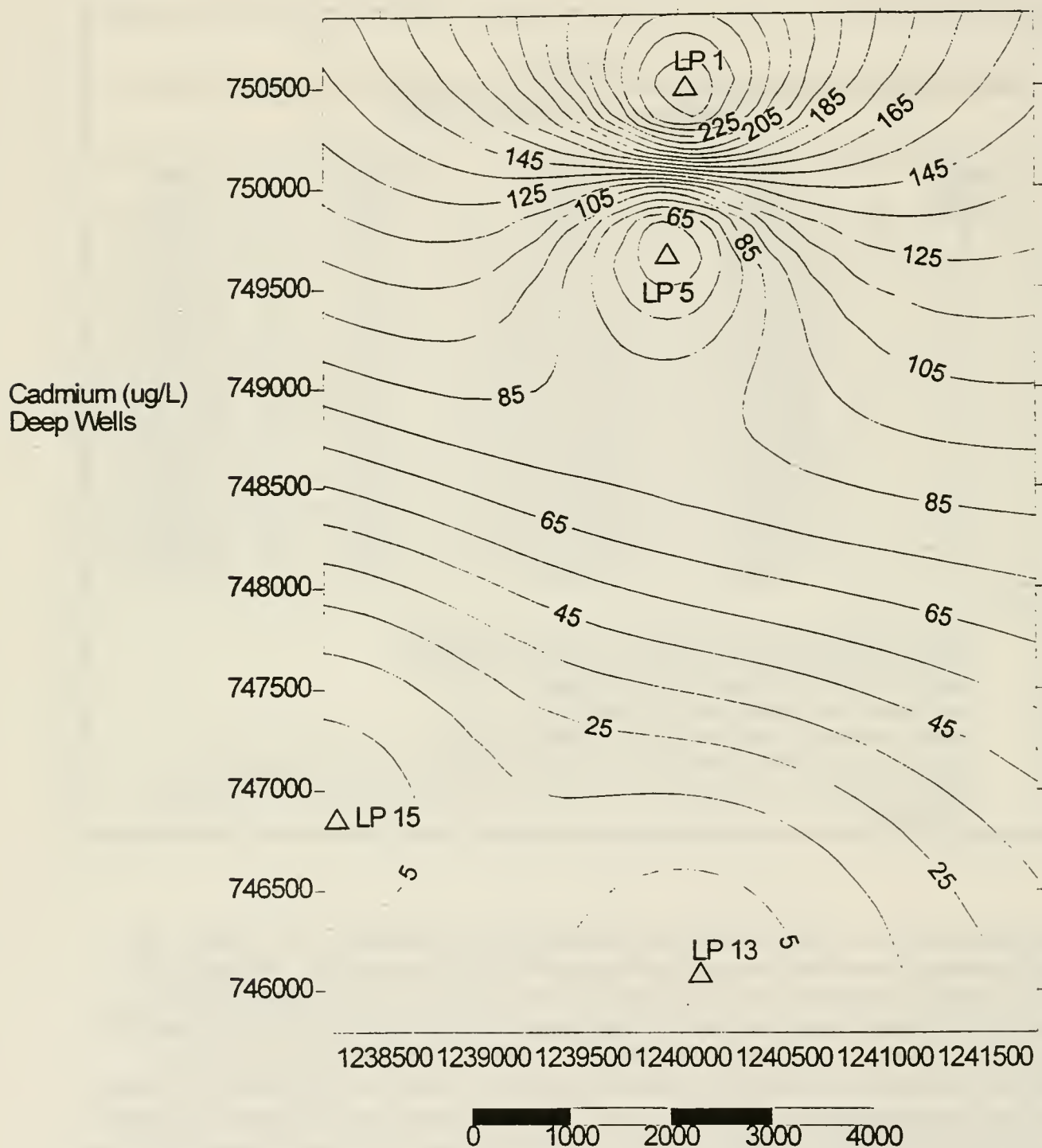


Figure 3-9A. Areal Extent of Injured Groundwater in the Butte Hill Alluvial Aquifer (Deep Wells): Cadmium. Source: Appendix IIIB.

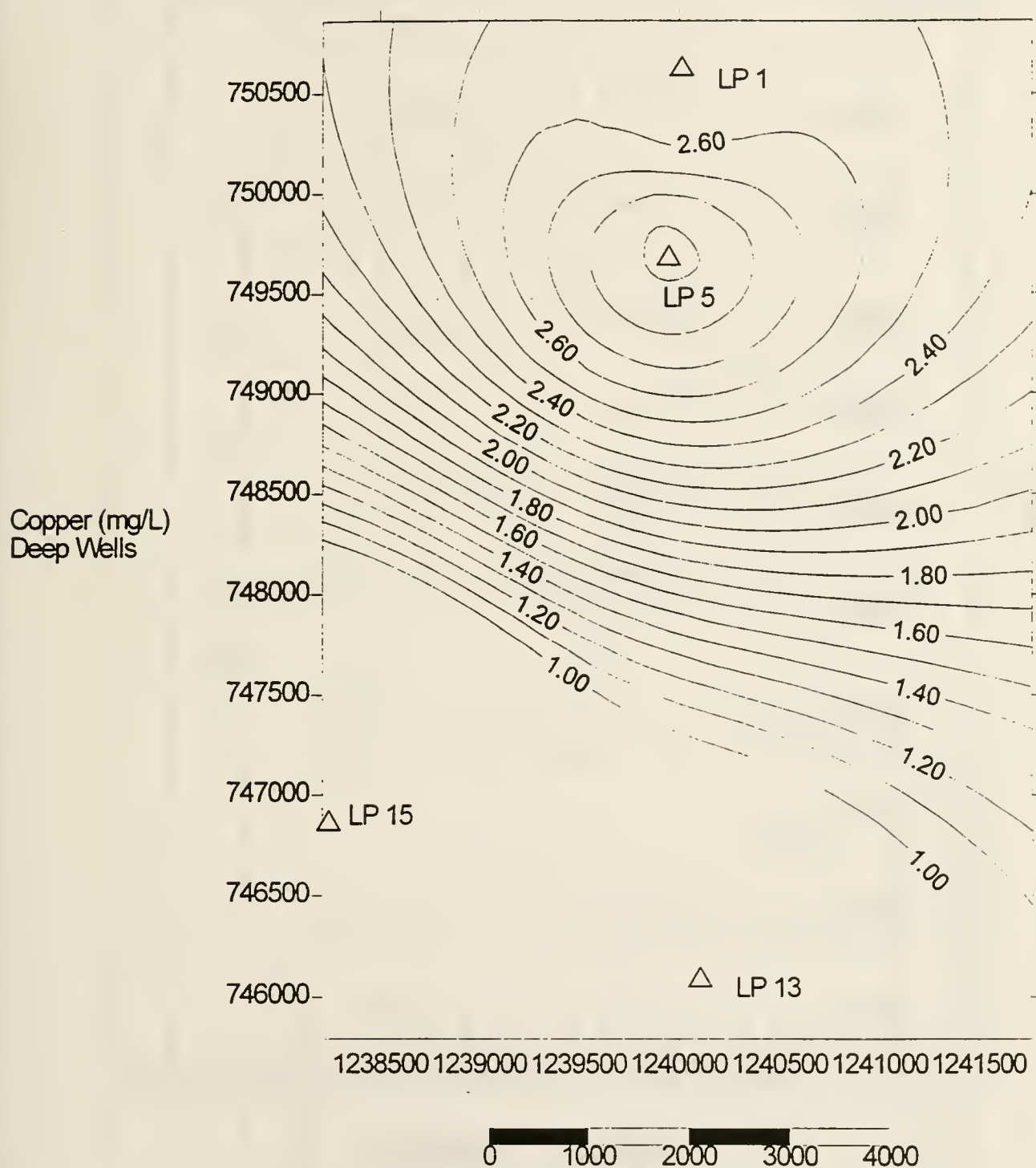


Figure 3-9B. Areal Extent of Injured Groundwater in the Butte Hill Alluvial Aquifer (Deep Wells): Copper. Source: Appendix IIIB.

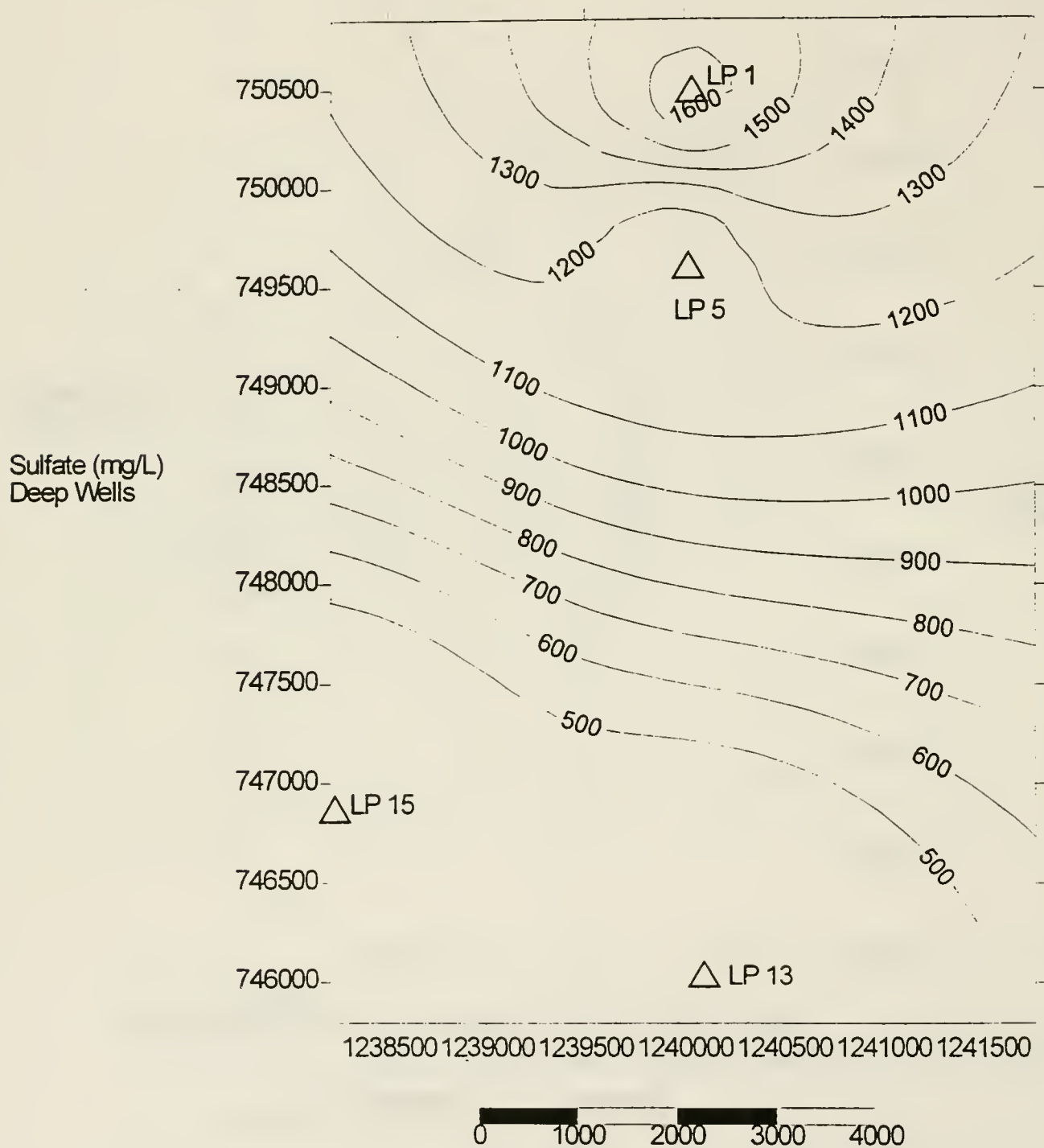


Figure 3-9C. Areal Extent of Injured Groundwater in the Butte Hill Alluvial Aquifer (Deep Wells): Sulfate. Source: Appendix IIIB.

Table 3-11
Information Used to Calculate Area and Volume of Injured Alluvial Groundwater in the Butte Hill Area

Well	Latitude/Longitude		Screen Interval (ft)	Average Depth (ft) (center of screen)	Average SWL (ft)	mg/l						
	East	North				Zn	Cu	Fe	Pb	As	SO ₄	Cd
LP1	1240026	750462	175-195	185	133	16.4	2.54	0.14	0.03	0.00	1,640	0.26
LP2	1240085	750456	127-157	142	134	66.0	78.1	0.36	0.03	0.01	5,650	3.43
LP3	1238704	750870	20-60	40	19	36.2	315	773	0.03	0.02	31,533	5.41
LP4	1239992	749728	115-155	135	90	84.5	5.97	0.11	0.02	0.00	3,097	0.30
LP5	1239961	749713	186-226	206	107	41.2	2.93	0.12	0.01	0.00	1,138	0.05
LP6	1241771	750230	95-105	100	108	145	0.14	0.03	0.00	0.00	609	0.00
LP7	1240026	750269	90-95	92.5	88	57.3	432	8.58	0.06	0.02	20,000	9.95
LP8	1239991	749542	79.5-94.5	87	59	45.0	413	0.82	0.07	0.02	24,000	6.76
LP9	1239223	749802	80-100	90	72	146	0.23	0.13	0.02	0.00	3,900	0.46
LP10	1241068	748332	130-160	145	121	16.3	0.91	0.04	0.03	0.00	160	0.00
LP12	1240038	746110	108-128	118	78	45.0	0.62	0.03	0.00	0.00	530	0.01
LP13	1240014	746118	215-235	225	84	33.6	0.70	0.03	0.00	0.00	310	0.00
LP14	1239052	745795	82-102	92	65	23.5	0.05	0.05	0.00	0.00	620	0.01
LP15	1238178	746903	215-235	225	84	27.1	0.01	0.03	0.00	0.00	310	0.01
LP16	1238212	746887	100-120	110	83	34.7	1.07	0.05	0.00	0.00	810	0.02

Source: Canonic, 1992a.

SWL = depth from ground surface to static water level.

Table 3-12
Surface Area, Volume, and Flux of Injured Alluvial Groundwater in the Butte Hill Area

Volume Calculations									
	Surface Area (sq ft)	Surface Area (acres)	Avg. Depth (ft)	Avg. SWL (ft)	Avg. Cont. GW Depth (ft)	Volume (cu ft)	Volume (acre-ft)	Volume (acre-ft) @ 20% Porosity	
Zn	2.20E+07	505	133	88.3	44.5	9.79E+08	22,500	4,500	
SO ₄	2.19E+07	503	135	86.9	48.3	1.06E+09	24,300	4,850	
Cd	2.10E+07	482	134	84.3	50.1	1.05E+09	24,200	4,830	
Cu	1.60E+07	367	125	89.1	35.6	5.69E+08	13,100	2,610	
Fe	5.25E+06	121	90.4	75.0	15.4	8.07E+07	1,850	371	
Pb	7.25E+04	1.67	89.8	73.5	16.3	1.18E+06	27.1	5.41	
Surface area = area exceeding relevant water quality standards.									
Average groundwater depth = average screened depth - SWL (Table 3-11).									
Flux Calculations									
Section (approx.)			T (sq ft/d)	n (from map)	CI (ft)	Q (cu ft/d)	Q (ac-ft/yr)		
Zn			79.5	9	25	17,900	150		
SO ₄			79.5	9	25	17,900	150		
Cd			79.5	9	25	17,900	150		
Cu			79.5	9	25	17,900	150		
Fe			79.5	3	25	5,960	50.0		
Pb			79.5	2	25	3,980	33.3		

Based on RI static water levels and transmissivity values.

$$Q = n * T * CI$$

Where:

Q: Discharge (cu. ft./day).

n: Number of flow tubes.

Avg. Depth = Average depth of wells with exceedences.

Avg. SWL = Average depth to water table for wells with exceedences.

Avg. Cont. GW Depth = Avg. Depth - Avg. SWL.

T: Transmissivity (sq. ft./day).

CI: Contour interval (ft.).

3.2.1.2.2 Area I

Plan view isopleth maps were constructed for arsenic, cadmium, copper, iron, lead, sulfate, and zinc for the area west of Montana street (Figures 3-10A through 3-10G) and for cadmium, copper, iron, lead, sulfate, and zinc in the Area I alluvial aquifer east of Montana Street (Figures 3-11A through 3-11F) using data in Appendix IIIA and the graphing program SURFER. The areal extent of injured alluvial groundwater is much greater east of Montana Street than west of Montana Street (Table 3-13). The areal extent of Area I groundwater both east and west of Montana Street that exceeds any relevant standard is shown in Figure 3-12.

For the area west of Montana Street the areal extent of the hazardous substance groundwater plumes decreases in the following order:

cadmium > sulfate > zinc > iron > lead > copper > arsenic.

For the area east of Montana Street the areal extent of the hazardous substance groundwater plumes decreases in a very similar order:

sulfate > zinc > cadmium > iron > lead > copper.

Arsenic concentrations do not exceed the MCL value of 50 µg/l east of Montana Street, and therefore no groundwater plume for arsenic is shown.

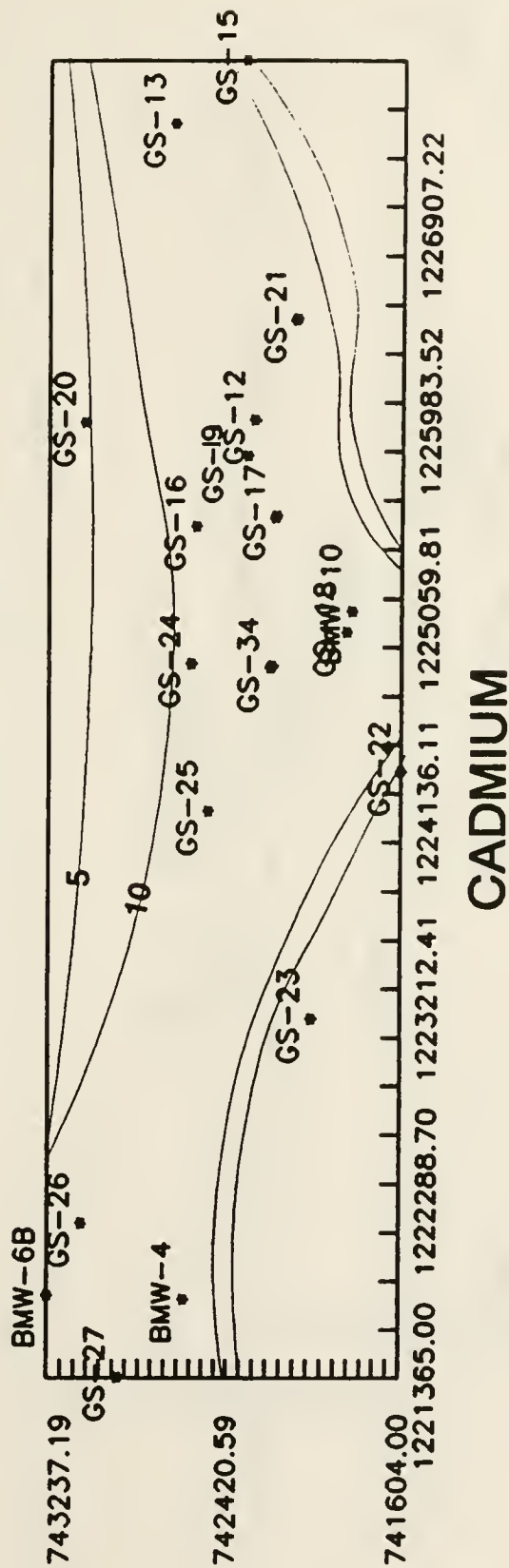
For the combined areas both east and west of Montana street, the areal extent of the hazardous substance groundwater plumes decreases in the following order:

sulfate > cadmium > zinc > iron > lead > copper > arsenic.

Isopleth maps for a number of other constituents were not constructed, but the following hazardous and other substances are also elevated in alluvial groundwaters above their MCL/SMCL values in wells that are at least 100 feet apart (see Table 2-2 and Appendix IIIA): aluminum, antimony, beryllium, chromium, fluoride, manganese, nickel, thallium and nitrate. Selenium and silver MCLs are exceeded in only one well each. Elevated nitrate levels may not be related to mining activity.

The areal extent of injured alluvial groundwater west and east of Montana Street and for the combined areas is presented in Table 3-13. A planimeter was used to estimate the area in the 2-D contour maps that exceed the MCL or SMCL value. The total areal extent of injured alluvial groundwater in Area I is given by the extent of the sulfate plume, which is 2.45×10^7 square feet (0.88 square miles or 562.5 acres). The plume of injured alluvial groundwater for cadmium is almost as large, i.e., 530 acres or 0.83 square miles. Moreover, the composite plume which includes all injured groundwater, is even larger than the sulfate plume (Figure 3-12).

SILVER BOW CREEK WELLS WEST OF MONTANA STREET



SILVER BOW CREEK WELLS WEST OF MONTANA STREET

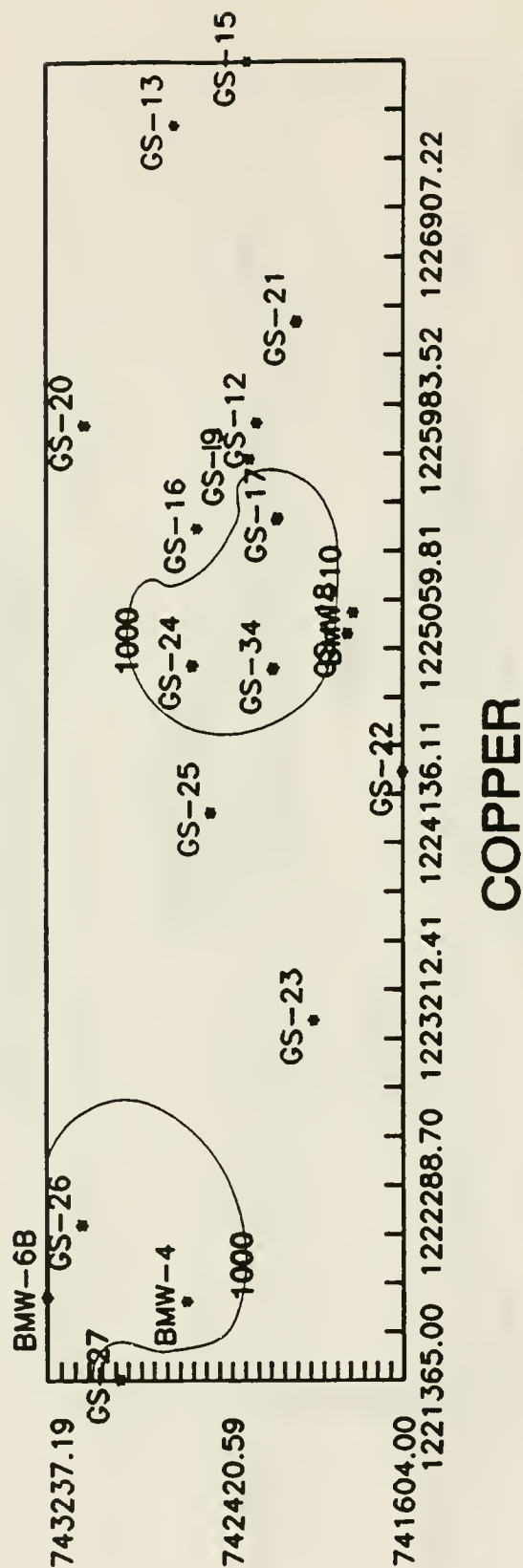


Figure 3-10C. Areal Extent of Injured Alluvial Groundwater in Area I West of Montana Street: Copper ($\mu\text{g/l}$).
Source: Appendix IIIA.

SILVER BOW CREEK WELLS WEST OF MONTANA STREET

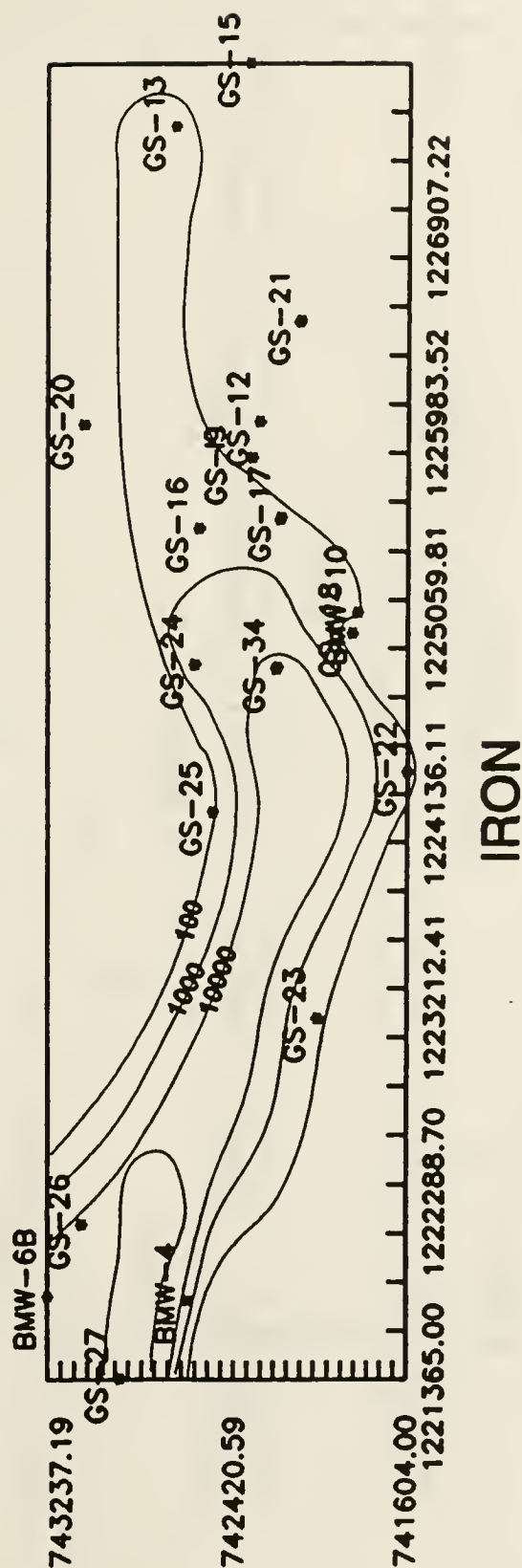


Figure 3-10D. Areal Extent of Injured Alluvial Groundwater in Area I West of Montana Street: Iron (µg/l).
Source: Appendix IIIA.

SILVER BOW CREEK WELLS WEST OF MONTANA STREET

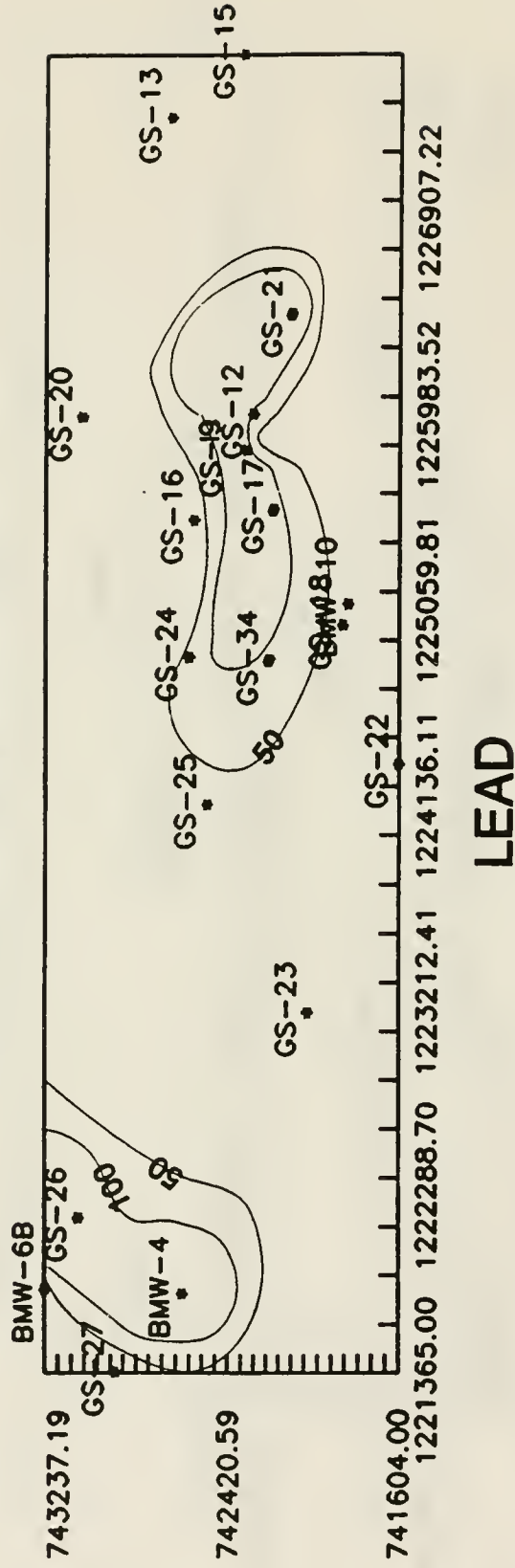
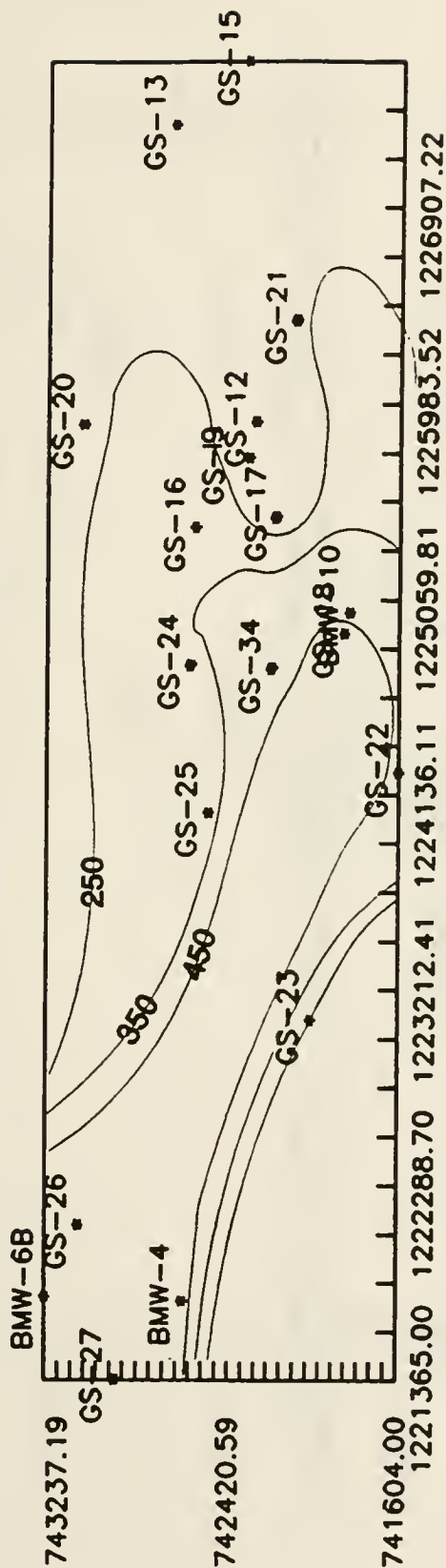


Figure 3-10E. Areal Extent of Injured Alluvial Groundwater in Area I West of Montana Street: Lead ($\mu\text{g/l}$).
Source: Appendix IIIA.

SILVER BOW CREEK WELLS WEST OF MONTANA STREET



SULFATE

Figure 3-10F. Areal Extent of Injured Alluvial Groundwater in Area I West of Montana Street: Sulfate ($\mu\text{g/l}$).
Source: Appendix IIIA.

SILVER BOW CREEK WELLS WEST OF MONTANA STREET

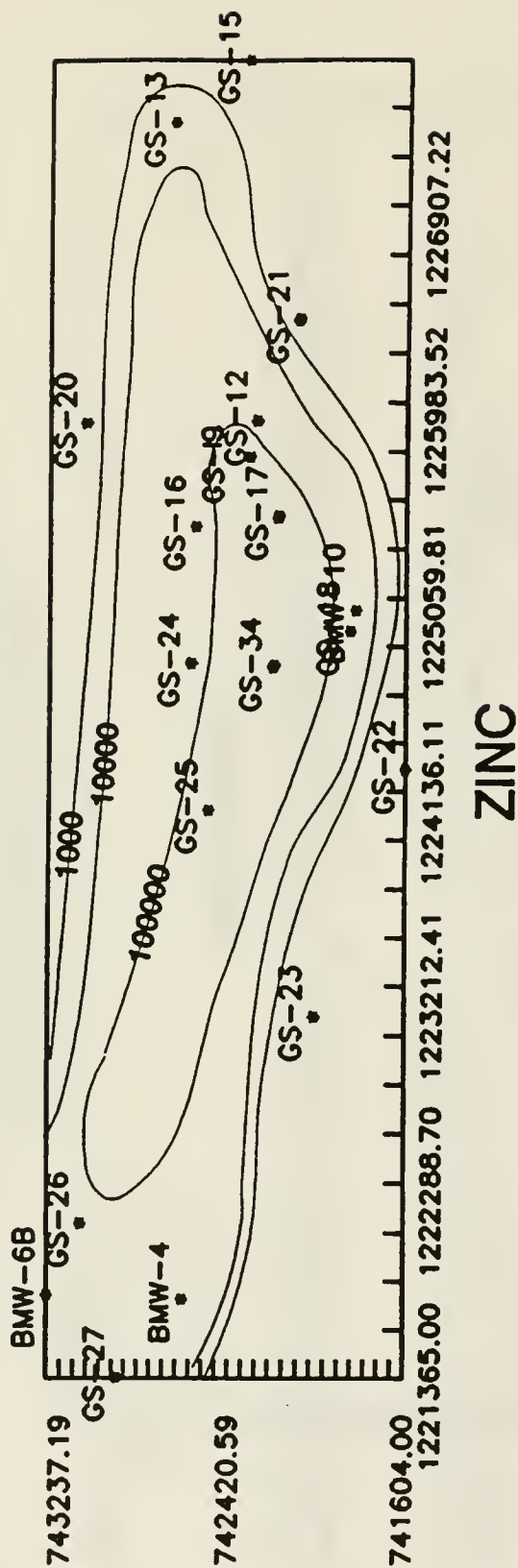


Figure 3-10G. Areal Extent of Injured Alluvial Groundwater in Area I West of Montana Street: Zinc ($\mu\text{g/l}$).
Source: Appendix IIIA.

SILVER BOW CREEK WELLS EAST OF MONTANA STREET

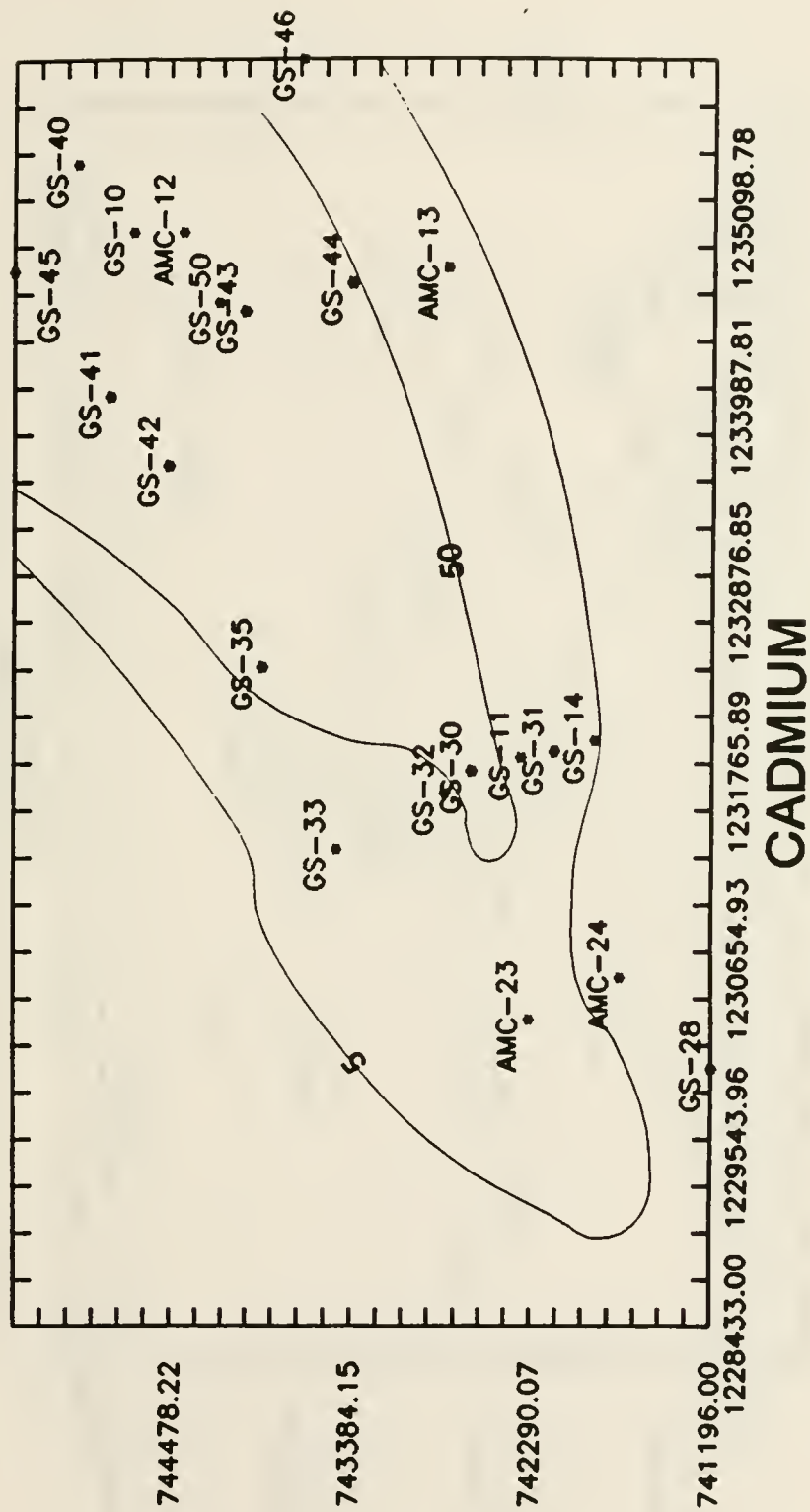


Figure 3-11A. Areal Extent of Injured Alluvial Groundwater in Area I East of Montana Street: Cadmium (µg/l).
Source: Appendix IIIA.

SILVER BOW CREEK WELLS EAST OF MONTANA STREET

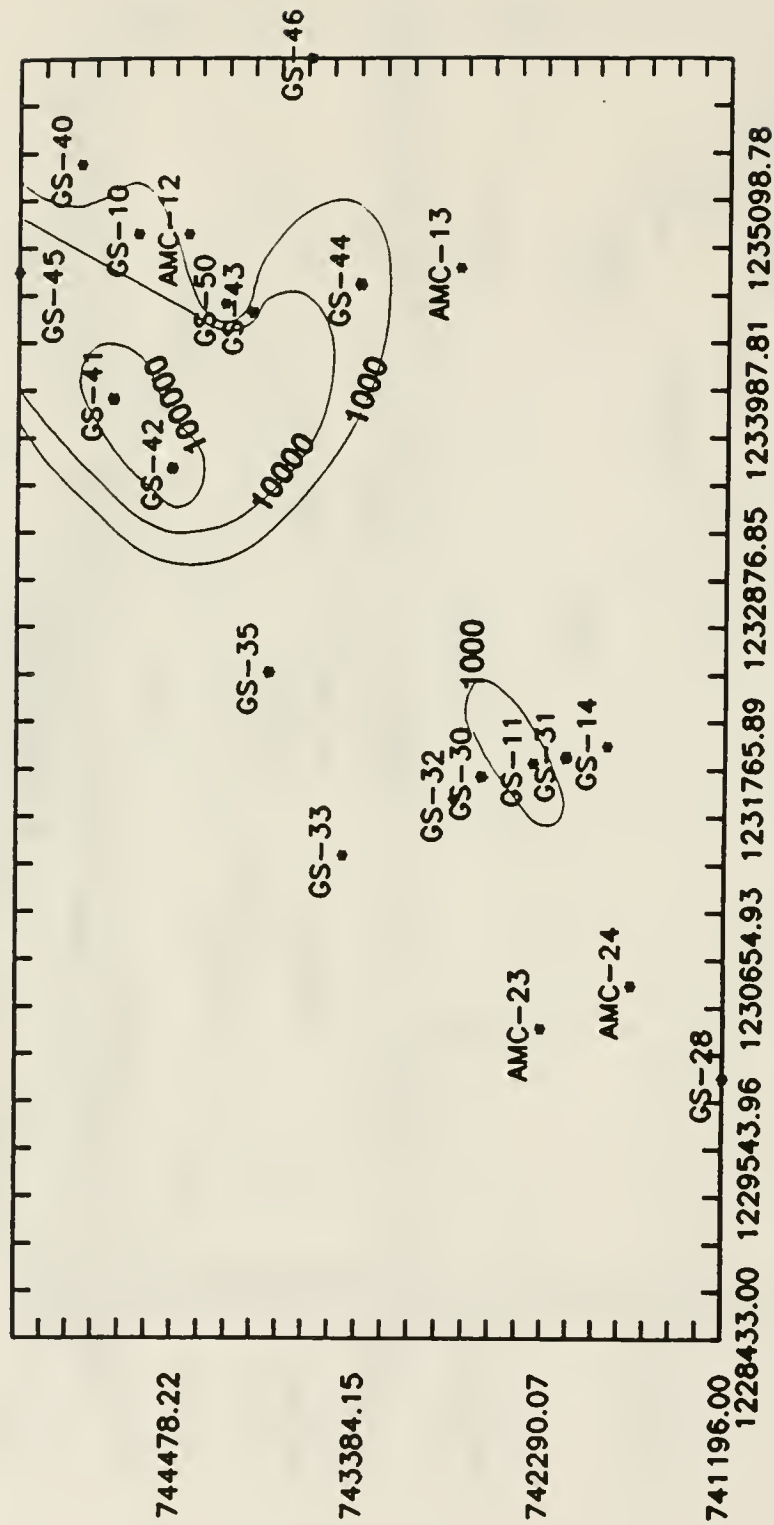
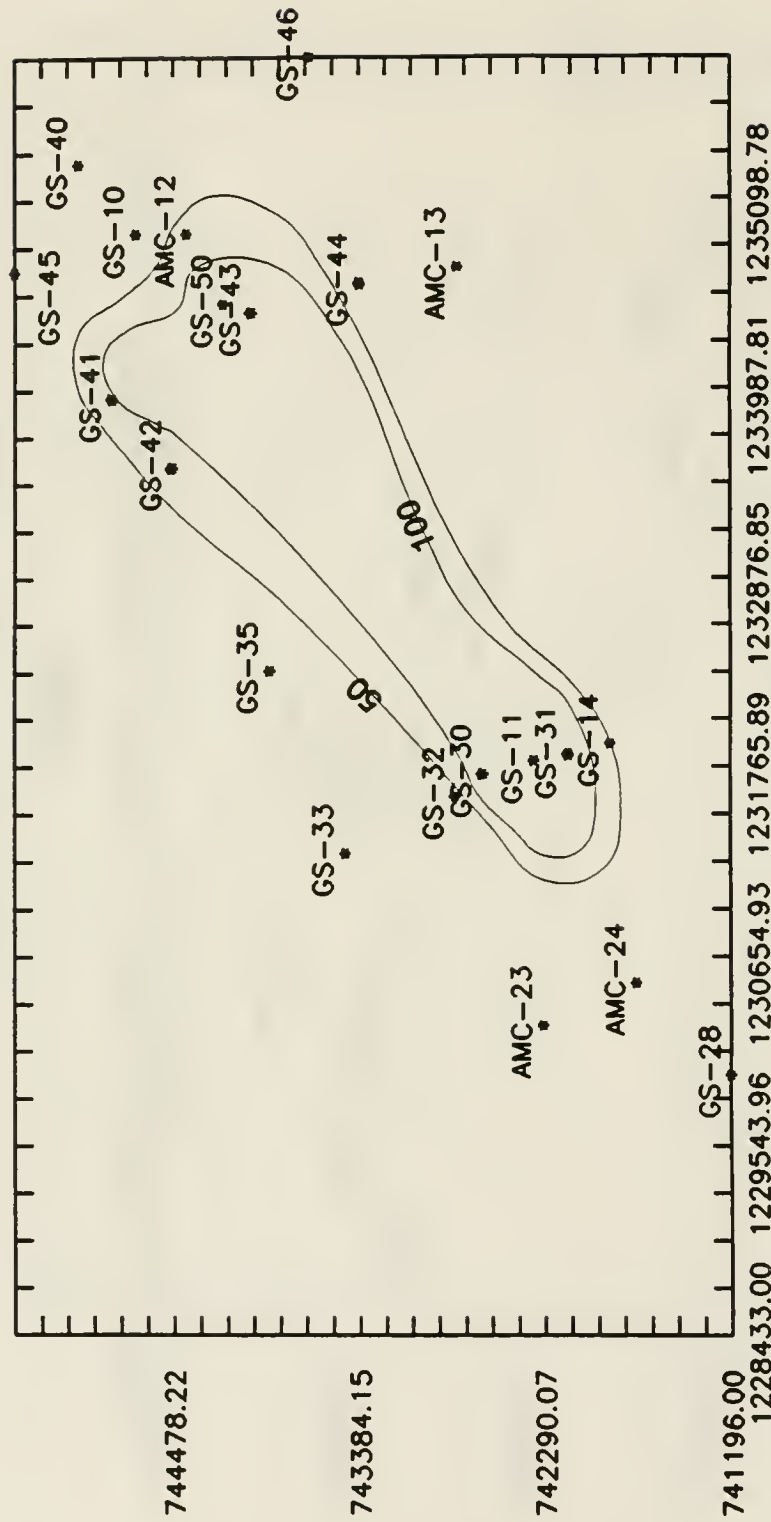


Figure 3-11B. Areal Extent of Injured Alluvial Groundwater in Area I East of Montana Street: Copper ($\mu\text{g/l}$).
Source: Appendix IIIA.

SILVER BOW CREEK WELLS EAST OF MONTANA STREET



LEAD

Figure 3-11D. Areal Extent of Injured Alluvial Groundwater in Area I East of Montana Street: Lead (µg/l).
Source: Appendix IIIA.

SILVER BOW CREEK WELLS EAST OF MONTANA STREET

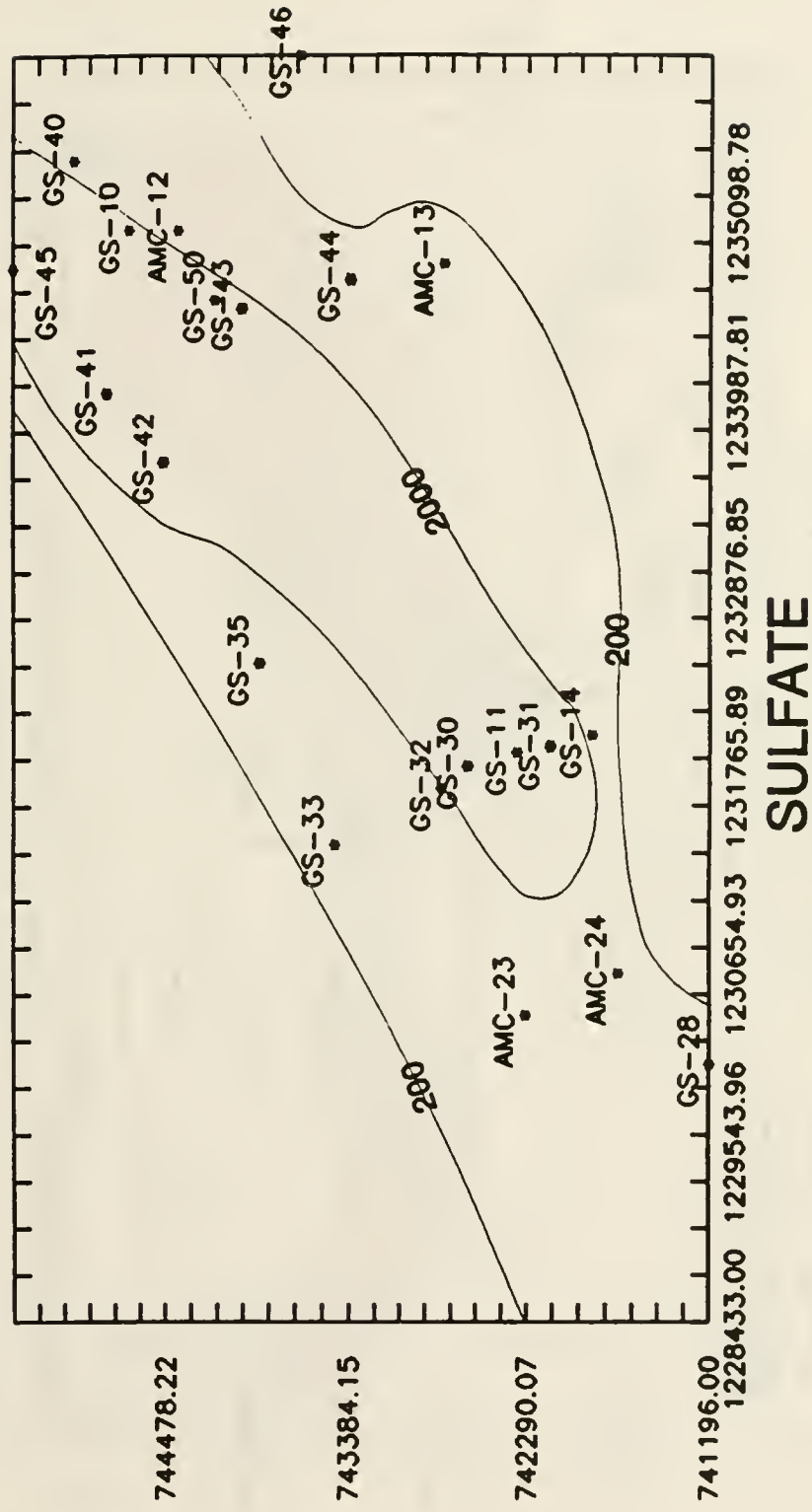


Figure 3-11E. Areal Extent of Injured Alluvial Groundwater in Area I East of Montana Street: Sulfate (mg/l).
Source: Appendix IIIA.

SILVER BOW CREEK WELLS EAST OF MONTANA STREET

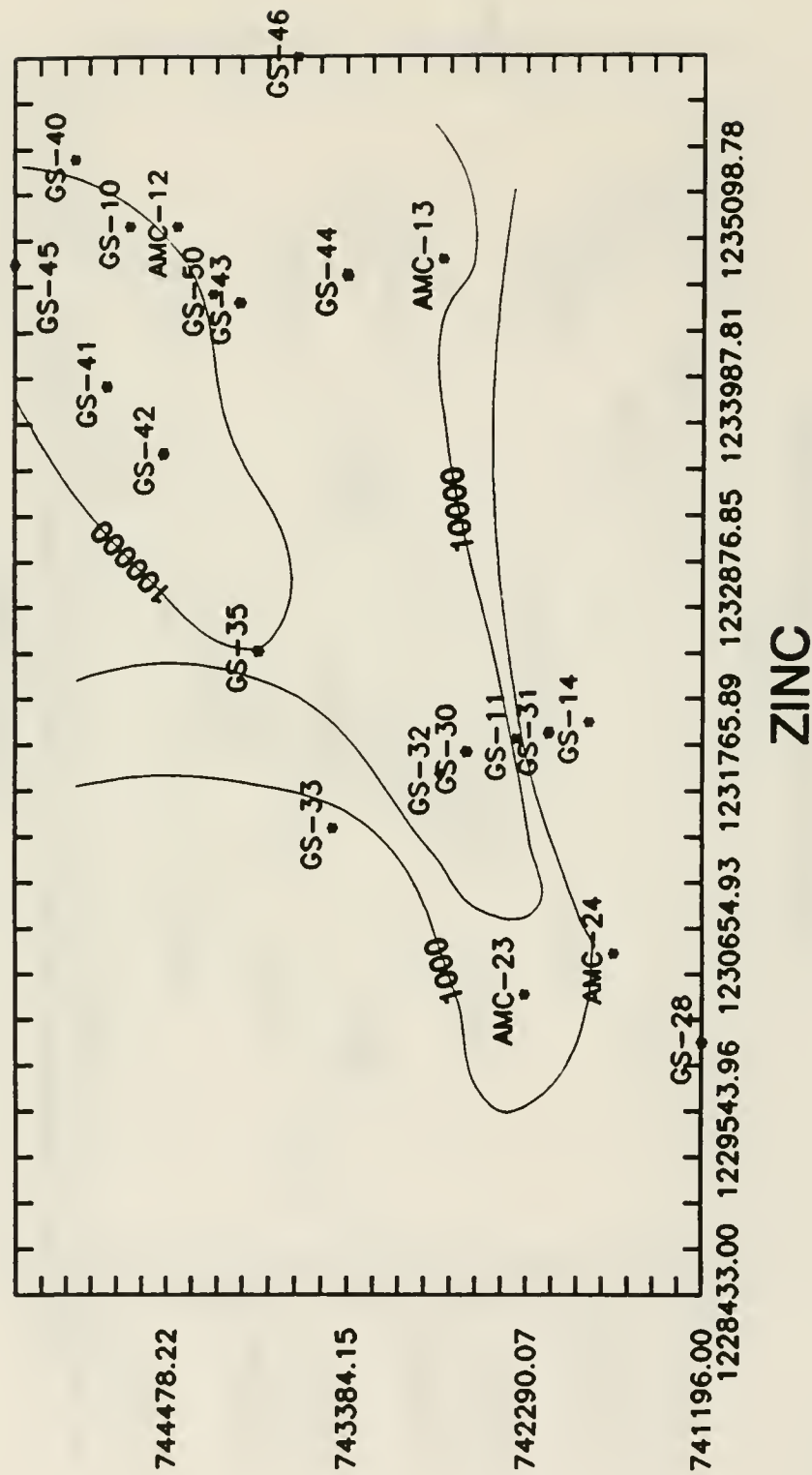


Figure 3-11F. Areal Extent of Injured Alluvial Groundwater in Area 1 East of Montana Street: Zinc (µg/l).
Source: Appendix IIIA.

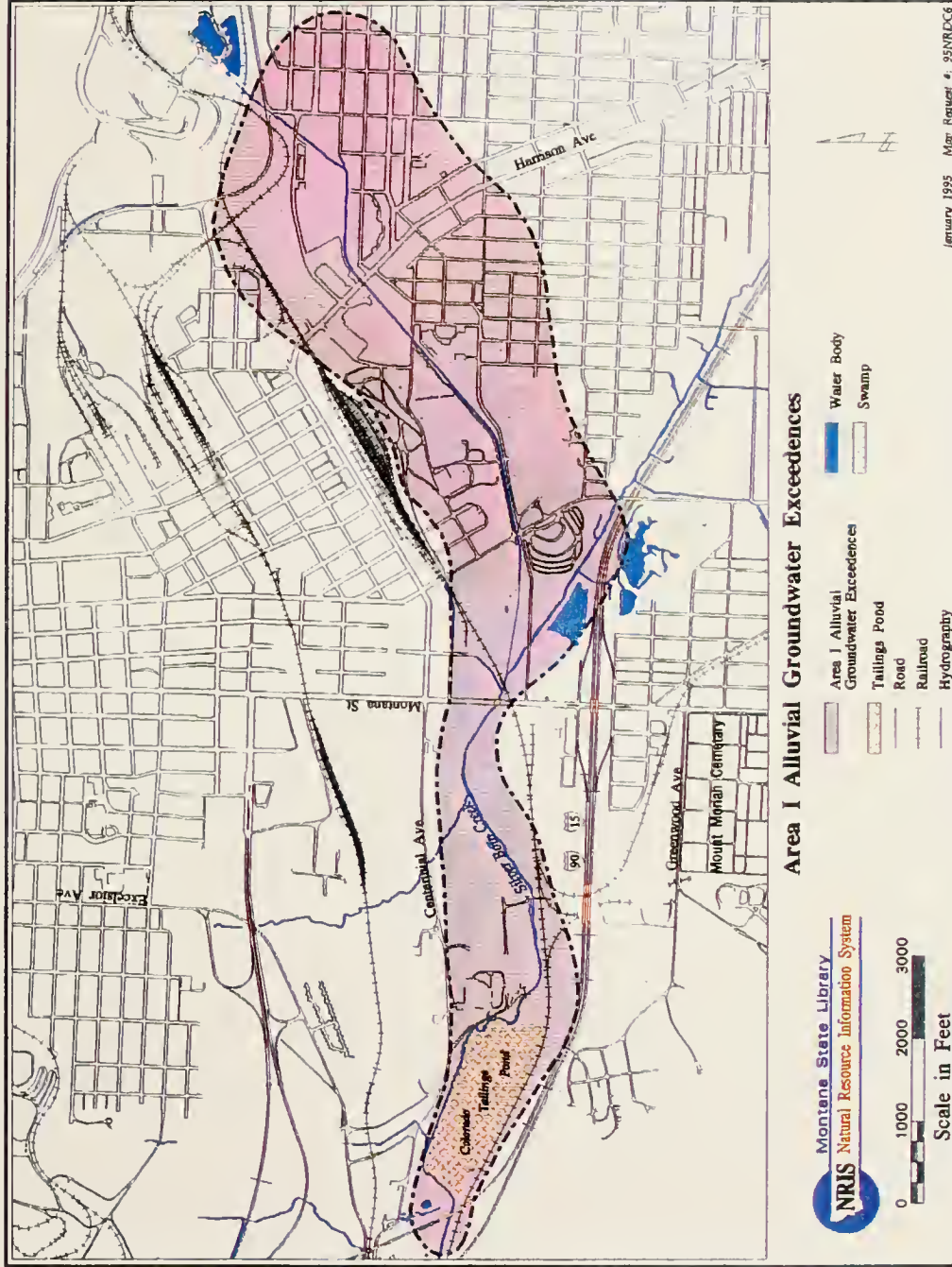


Figure 3-12. Areal Extent of Injured Alluvial Groundwater in Area I Exceeding Any Relevant Standard. Source: Appendix IIIA.

Volume Calculations

West of Montana Street							
	Surface Area (sq ft)	Approx. Depth C-C'	Approx Depth D-D' .	Average Depth	Avg. Cont. GW Depth (ft)	Volume (cu ft)	Volume @ 20% Porosity (cu ft)
Fe	5.35E+06	8	65	36.5	27.5	1.47E+08	2.94E+07
Zn	7.29E+06	21	65	43.0	34.0	2.48E+08	4.96E+07
SO ₄	8.02E+06	20	65	42.5	33.5	2.69E+08	5.37E+07
Cd	8.36E+06	21	60	40.5	31.5	2.63E+08	5.27E+07
As	1.52E+06	19	65	42.0	33.0	5.02E+07	1.00E+07
Pb	2.70E+06	14	45	29.5	20.5	5.54E+07	1.11E+07
Cu	2.11E+06	15	65	40.0	31.0	6.54E+07	1.31E+07
East of Montana Street							
	Surface Area (sq ft)	Approx. Depth A-A'	Approx. Depth B-B'	Average Depth (ft)	Avg. Cont. GW Depth (ft)	Volumie (cu ft)	Volumie @ 20% Porosity (cu ft)
Fe	1.43E+07	50	180	115.0	97.6	1.40E+09	2.79E+08
Zn	1.48E+07	25	210	117.5	100.1	1.48E+09	2.96E+08
SO ₄	1.65E+07	55	210	132.5	115.1	1.90E+09	3.80E+08
Cd	1.47E+07	40	210	125.0	107.6	1.58E+09	3.16E+08
As	0	—	—	—	—	0	0
Pb	3.86E+06	25	60	42.5	25.1	9.69E+07	1.94+07
Cu	1.64E+06	25	250	137.5	120.1	1.97E+08	3.94+07
Total East and West							
	Surface Area (sq ft)	Volume (cu ft)	Volume @ 20% Porosity (cu ft)				
Fe	1.97E+07	1.54E+09	3.09E+08				
Zn	2.21E+07	1.73E+09	3.46E+08				
SO ₄	2.45E+07	2.17E+09	4.34E+08				
Cd	2.31E+07	1.85E+09	3.69E+08				
As	1.52E+06	5.02E+07	1.00E+07				
Pb	6.56E+06	1.52E+08	3.04E+07				
Cu	3.75E+06	2.62E+08	5.25E+07				

Based on contour maps and cross sections.
 Surface area = area exceeding relevant water quality standards.

Flux Calculations						
Section (approx.)	T (range)	n (from map)	Q1 (cu ft/d)	Q2 (cu ft/d)	Q (avg.) (cu ft/d)	Q (avg.) (ac.-ft/yr)
B - B'	45 - 400	10	900	8,000	4,450	37.3
C - C'	2400 - 6000	16	76,800	192,000	134,400	61,126.2
D - D'	270 - 380	7	3,780	5,320	4,550	38.1

Based on Phase II RI static water levels and transmissivity values.
 $Q = n \times T \times CI$
 Where:

Q: Discharge (cu ft/d).

T: Transmissivity (sq ft/day).

Avg. Cont. GW Depth = Avg. depth of contaminated groundwater = Avg. Depth - Avg. SWL.

n: Number of flow tubes.

CI: Contour interval (= 2 ft).

Avg. SWL West of Montana St. = 9 ft
Avg. SWL East of Montana St. = 17.4 ft.

3.2.2 Volume of Injured Groundwater

3.2.2.1 Bedrock Aquifer

Table 3-10 presents information used to calculate the volume of injured bedrock groundwater in the Butte Mine Flooding area. The volume was calculated using mine projection maps. Fifty-one mine projection maps exist, and each sheet represents one level (100 feet) of mine workings (mine workings extend to approximately 5,100 feet below the ground surface). Maps from ten evenly-spaced working mine levels were used for volume calculations (Table 3-14).

The areas were determined by outlining each map based on the farthest extent of workings in both the West Camp and the East Camp. The result was a polygon with 4 to 11 points depending on the complexity of the level. The area for each level was calculated by dividing each area into triangles and summing their areas. Polygon areas were verified by digitizing each sheet and calculating an area using ARC/INFO software.

Volumes were calculated by integrating the determined areas into a solid volume and applying porosity values for the bedrock aquifer and mined "porosity" to account for the total void volume of the mine workings. Fracture porosity in the bedrock is conservatively estimated to be 1%; mined porosity is estimated to be 0.23%.

Volumes for four conditions are presented in Table 3-13. The first condition (Base of Pit to 5,100 level) calculates a volume for the area from the base of the Pit to the deepest extent of mine workings (5,100 feet below ground surface). The second condition considers the volume of bedrock aquifer with mine workings below the present groundwater level (SWL - static water level), using an elevation of 5,080 feet, to the deepest extent of mining. The water elevation in the Berkeley Pit was approximately 5,080 feet in October 1994 and rises 2 to 3 feet per month. The approximated current water elevation used in this report is 5,080 feet.

The third condition uses the action level for the East Camp (elevation = 5,410 feet). A volume was calculated using this elevation, which corresponds to the 450-foot level of the Kelley Mine and the deepest extent of mining. The action level will be used to estimate the volume of injured bedrock groundwater.

The fourth condition calculates the solid volume from the base of the pit to the 3,900 level. CDM/FPC (1989) estimated the mined volume of 4.6×10^8 cubic feet from the base of the Berkeley Pit to the Kelley Mine pump station on the 3900 level. Comparison of this to the solid volume indicates a mine-to-rock ratio of 0.23 percent.

Table 3-14
Volume of Injured Groundwater in the Butte Hill Area

I. Volume of Groundwater in Bedrock Using Four Conditions						
Conditions	Solid Volume (no porosity)	Groundwater Volume (1% porosity)		Groundwater Volume (1.23% porosity)		
	Cu Ft	Cu Ft	Acre-Ft	Cu Ft	Acre-Ft	Billion Gallons
1. Base of Pit to 5,100 level	3.27E+11	3.27E+09	75,100	4.02E+09	92,300	30.1
2. Below present SWL (5,080)	4.21E+11	4.21E+09	96,700	5.18E+09	119,000	38.7
3. Below Action Level (5,410)	4.64E+11	4.64E+09	107,000	5.71E+09	131,000	42.7
4. Base of Pit to 3,900 level	1.99E+11	1.99E+09	45,700	2.45E+09	56,200	18.3
Fracture porosity is estimated at 1%. CDM/FPC (1989) estimated the volume mined from the 3900 level to base of Pit at 4.6E+08 cubic feet or 0.23% of total solid volume.						
II. Volume of Water in the Berkeley Pit						
Elevation (ft)	Area at Contour (sq ft)	Volume				
		Cu Ft	Acre-Ft	Billion Gallons		
5,043	9.63E+06	2.79E+09	6.41E+04	20.9		
5,410	—	8.56E+09	1.96E+05	64.0		
5,443	2.29E+07	9.28E+09	2.13E+05	69.4		
Sources: Canonie, 1993a; Canonie, 1993b; and U.S. EPA, 1994.						

Injured bedrock groundwater volumes were based on (1) 1 percent fracture porosity; and (2) 1 percent fracture porosity plus an additional 0.23 percent mined volume (= 1.23%). Volumes for each of these assumptions are presented in Table 3-14. A porosity value of 1.23 was used as the best estimate of total porosity of the injured bedrock aquifer in the Butte Mine Flooding area because it uses a conservative (low) estimate for fracture porosity and includes the porosity to account for the mine workings. Volumes of injured groundwater at both the action level (elevation = 5,410 feet) and the present water level (5,080 feet) are presented in Table 3-14. Based on a porosity of 1.23% and using the action level of 5,410 feet elevation, the volume of injured groundwater in the bedrock aquifer on Butte Hill is estimated to be $5.71 \times 10^9 \text{ ft}^3$ (131,000 acre-feet or 42.7 billion gallons). At the approximate current water level of 5,080 feet, the volume of injured groundwater in the bedrock aquifer is $5.18 \times 10^9 \text{ ft}^3$ (119,000 acre-feet or 38.7 billion gallons).

The volume of water in the Berkeley Pit at an elevation of 5,443 feet, just above the action level of 5,410 feet, was calculated at $9.28 \times 10^9 \text{ ft}^3$ (2.13×10^5 acre-feet or 69.4 billion gallons) (Canonie, 1993a,b) (Table 3-14). At the action level, the volume of water in the Berkeley Pit is estimated to be $8.56 \times 10^9 \text{ ft}^3$ (1.96×10^5 acre-feet or 64 billion gallons) (U.S. EPA, 1994). The volume of pit water at the action level is added to the volume of injured bedrock aquifer groundwater below the action level for a total of $1.43 \times 10^{10} \text{ ft}^3$ (327,000 acre-feet or 107 billion gallons) of injured bedrock groundwater in the Butte Mine Flooding area at the action level.

The total volume at the action level will be used as the best estimate of injured bedrock groundwater in the Butte Hill area. The volume of injured bedrock groundwater calculated in the Record of Decision (ROD) (U.S. EPA, 1994) is higher than the estimate calculated above. In the ROD, the volume of injured bedrock groundwater in underground workings and fractures is estimated at 61.1 billion gallons instead of 42.7 billion gallons (U.S. EPA, 1994). The discrepancy may result from the different methods of calculating the extent of injured bedrock aquifer, although the ROD does not provide details on calculation methods.

3.2.2.2 Alluvial Aquifer

3.2.2.2.1 Butte Hill

Volume of injured groundwater in the Butte Hill alluvial aquifer was estimated based on 2-D plan view isopleth maps (Figures 3-9A through 3-9C) and is presented in Table 3-12. Zinc, copper, iron, cadmium, lead, and sulfate concentrations exceeded relevant standards. The SMCL value for sulfate was exceeded in all wells considered except well LP10 (see Table 3-11). The volume of contaminated groundwater was estimated using the average contaminated groundwater depths in Table 3-11 and the contoured area that exceeded the relevant standards.

A porosity of 20% was used for calculating the volume of injured groundwater for each of the constituents (conservative average value for silty sand; Freeze and Cherry, 1979). The volumetric extent of injured alluvial groundwater in the Butte Hill area at 20% porosity is 4,850 acre-feet (2.12×10^8 ft³ or 1.59 billion gallons), as represented by the sulfate plume. The volumetric extent of the cadmium plume (4,830 acre-feet) is only slightly less than that for sulfate.

3.2.2.2.2 Area I

Injury of alluvial aquifer groundwater in parts of Area I is very discontinuous for certain metals. Contamination "hot spots" exist around and downgradient from known sources of hazardous substances (buried tailings, surface tailings and other mining waste deposits, etc.). As discussed above, the areal extent of injured groundwater in the MSD area is greater than that in Lower Area I where the plumes are more confined, in part because of their proximity to groundwater discharge areas. In addition, because of the greater depth to bedrock in the MSD area, groundwater injury may extent to greater depths in the alluvial aquifer east of Montana Street than west of Montana Street. The graphing program Axum[®] (TriMetrix, Inc., 1992) was used to create 2-D cross-sectional contour maps to better estimate the depth of injured groundwater in Area I.

Both the plan view 2-D contour maps presented earlier (Figures 3-10 and 3-11) and cross-sectional (vertical) 2-D contour maps constructed for Area I were used to estimate the volumetric extent of injured groundwater. Figure 3-13A and B shows the location of the cross sections and wells used to develop the cross-sectional isopleth maps. The isopleth maps for Area I were constructed for four cross-sections oriented approximately perpendicular to Silver Bow Creek/Metro Storm Drain: A-A' and B-B' (east of Montana Street) and C-C' and D-D' (west of Montana Street). The following wells were used in these cross-sections: A-A' = GS33, GS32, GS30D, GS30S, GS11, GS31D, GS31S, GS14; B-B' = GS45, GS50, GS43D, GS43S, GS44D, GS44S, AMC-13; C-C' = GS20, GS16, GS17D, GS17S, GS22; D-D' = BMW-6B, BMW-4A, BMW-4T, BMW-4B. All isopleth maps were constructed using 1989 Phase II RI data for Area I (Appendix IIIA). Average values for the two 1989 sampling dates were used if they were within 20% RPD (relative percent difference = difference of two values divided by their mean). If not within 20% RPD, the 1989 value closest to the 1990 sampling value was used. All concentrations values shown are in µg/l, except for sulfate, which is in mg/l. The depth values on the y axis represent depth below the land surface.

Representative cross-sectional isopleth maps are presented for the area east of Montana Street in Figure 3-14A through 3-14C (copper, lead and zinc for A-A') and Figure 3-14D through 3-14F (iron, lead and sulfate for B-B'). Representative cross-sectional isopleth maps are also presented for the area west of Montana Street in Figure 3-15A through 3-15D (copper, lead, sulfate and zinc for C-C') and Figure 3-15E through 3-15F (iron and zinc for D-D').

SILVER BOW CREEK WELLS EAST OF MONTANA STREET

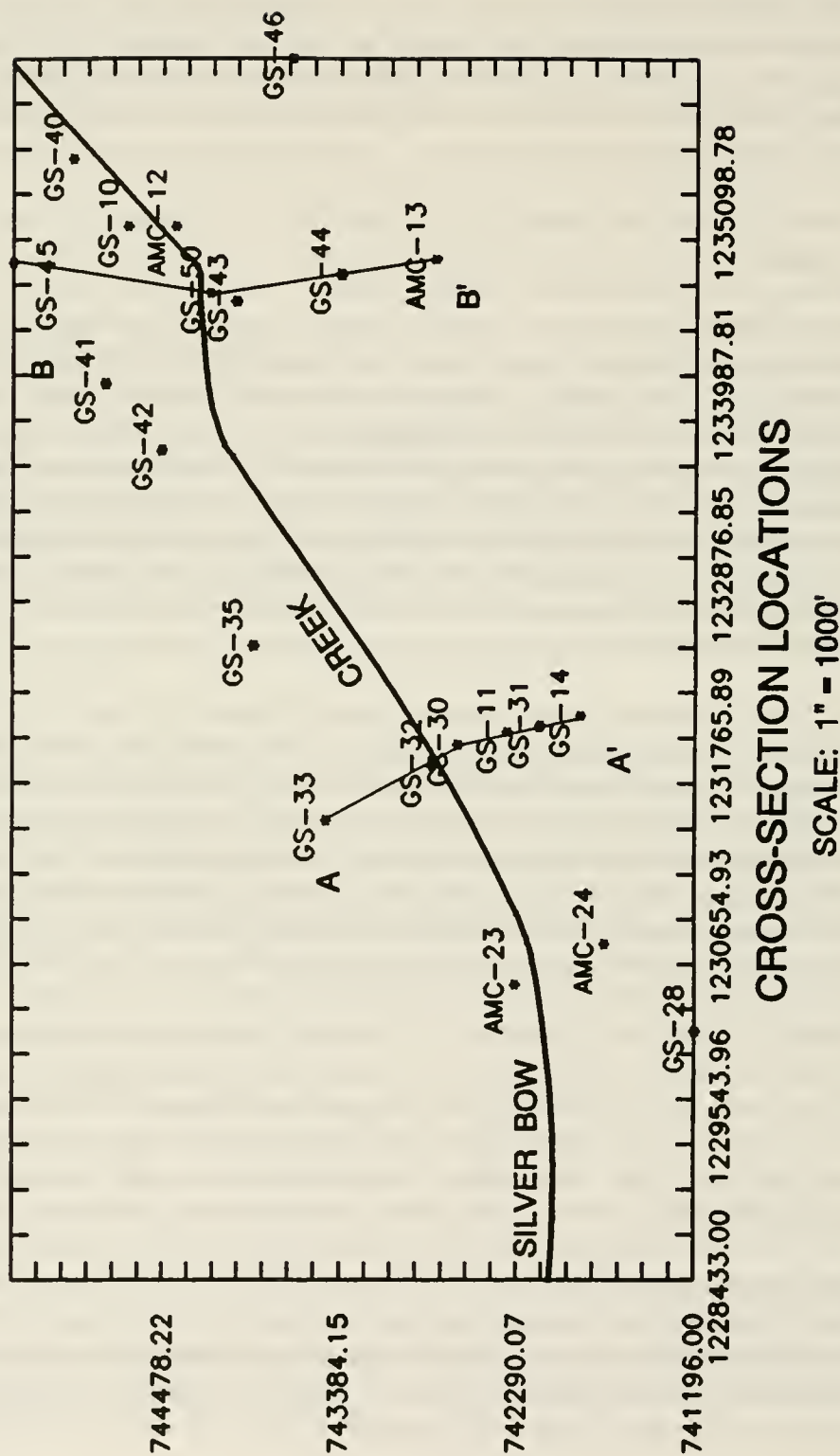


Figure 3-13A. Location of Cross Sections and Wells Used in Cross-Sectional Isopleth Maps: East of Montana Street.

SILVER BOW CREEK WELLS WEST OF MONTANA STREET

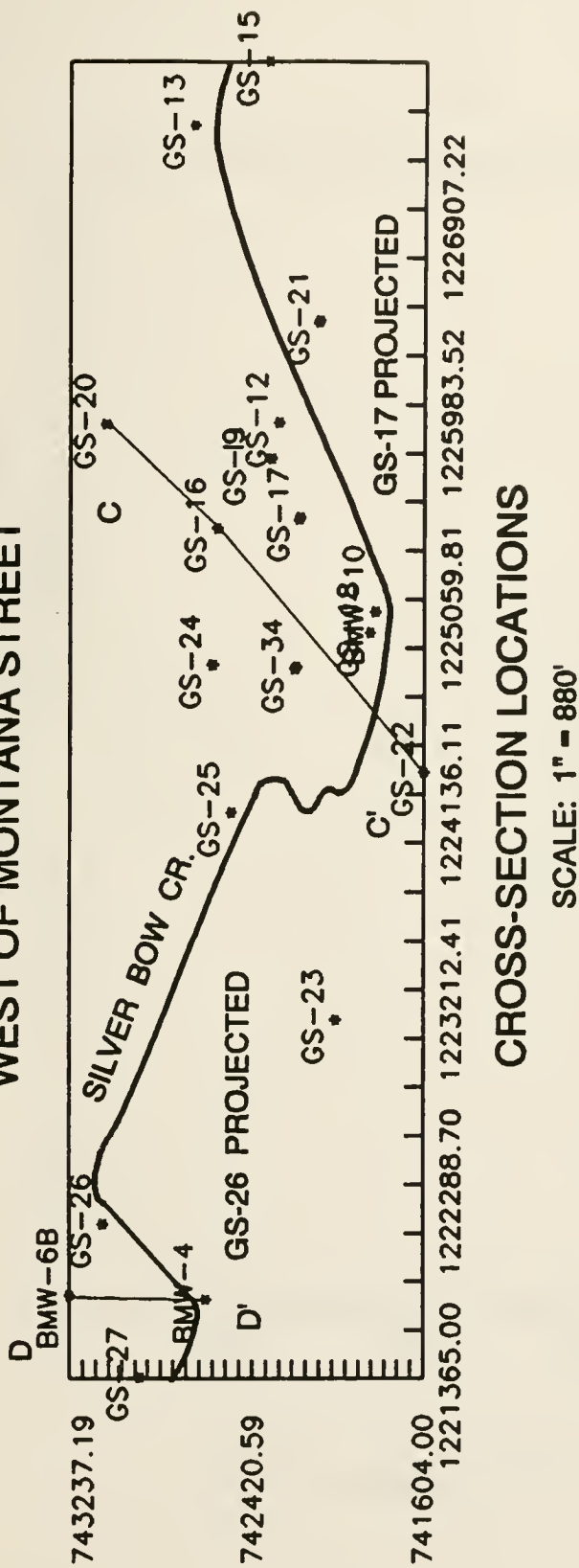


Figure 3-13B. Location of Cross Sections and Wells Used in Cross-Sectional Isopleth Maps: West of Montana Street.

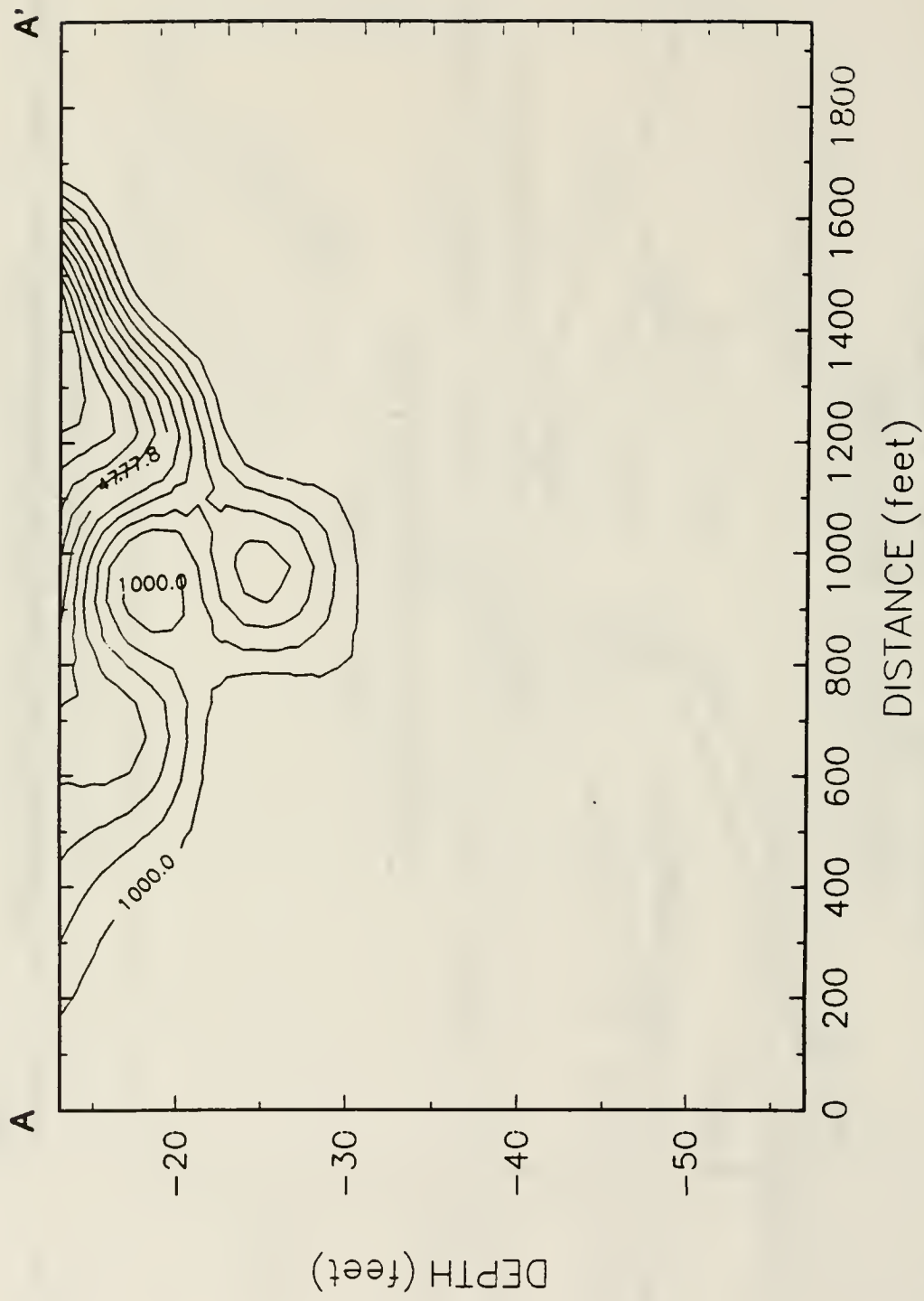


Figure 3-14A. Cross-Sectional Isopleth Map for Area I East of Montana Street: Copper (µg/l), A-A'.
Source: Appendix IIIA.

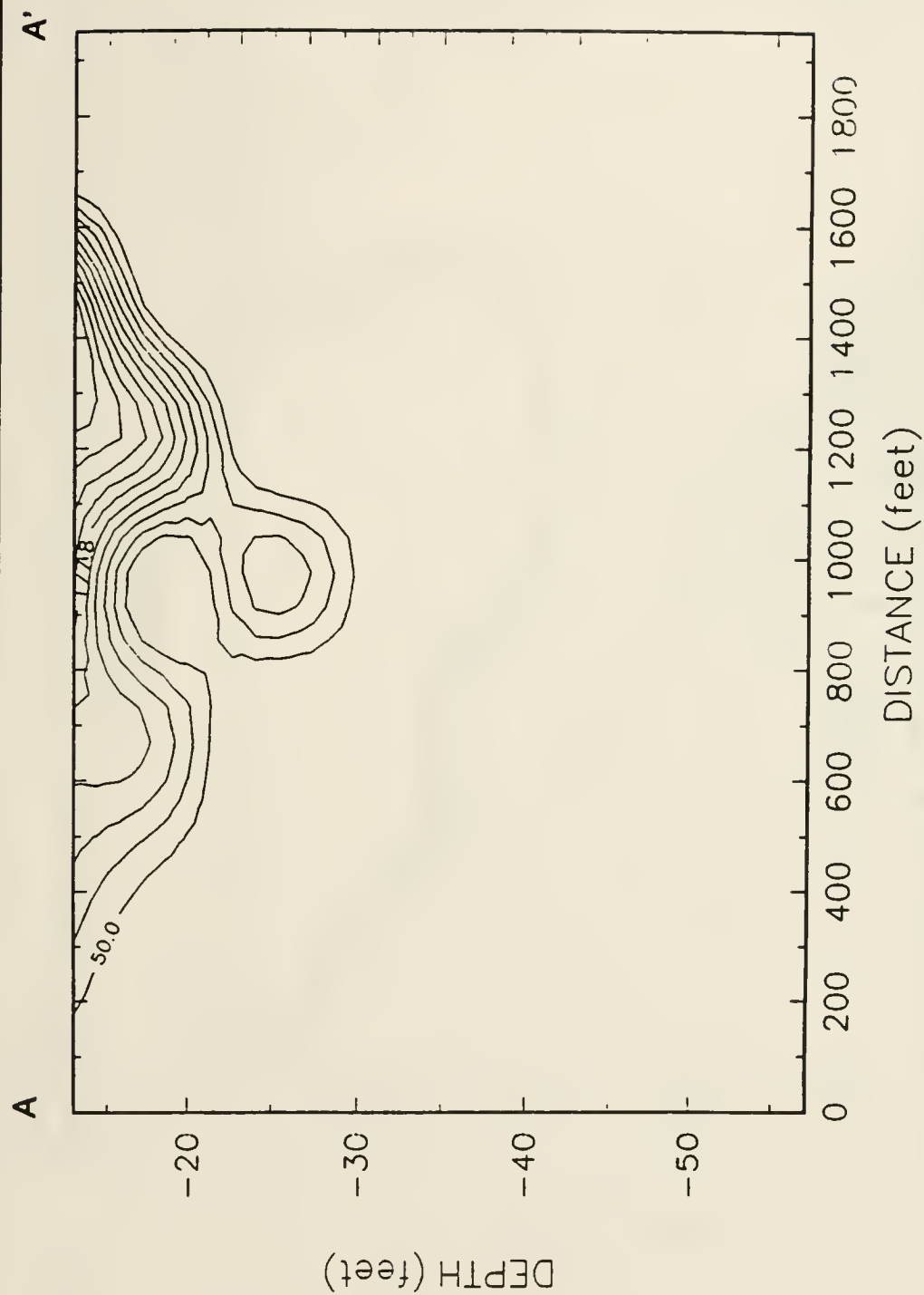


Figure 3-14B. Cross-Sectional Isopleth Map for Area I East of Montana Street: Lead (µg/l), A-A'. Source: Appendix IIIA.

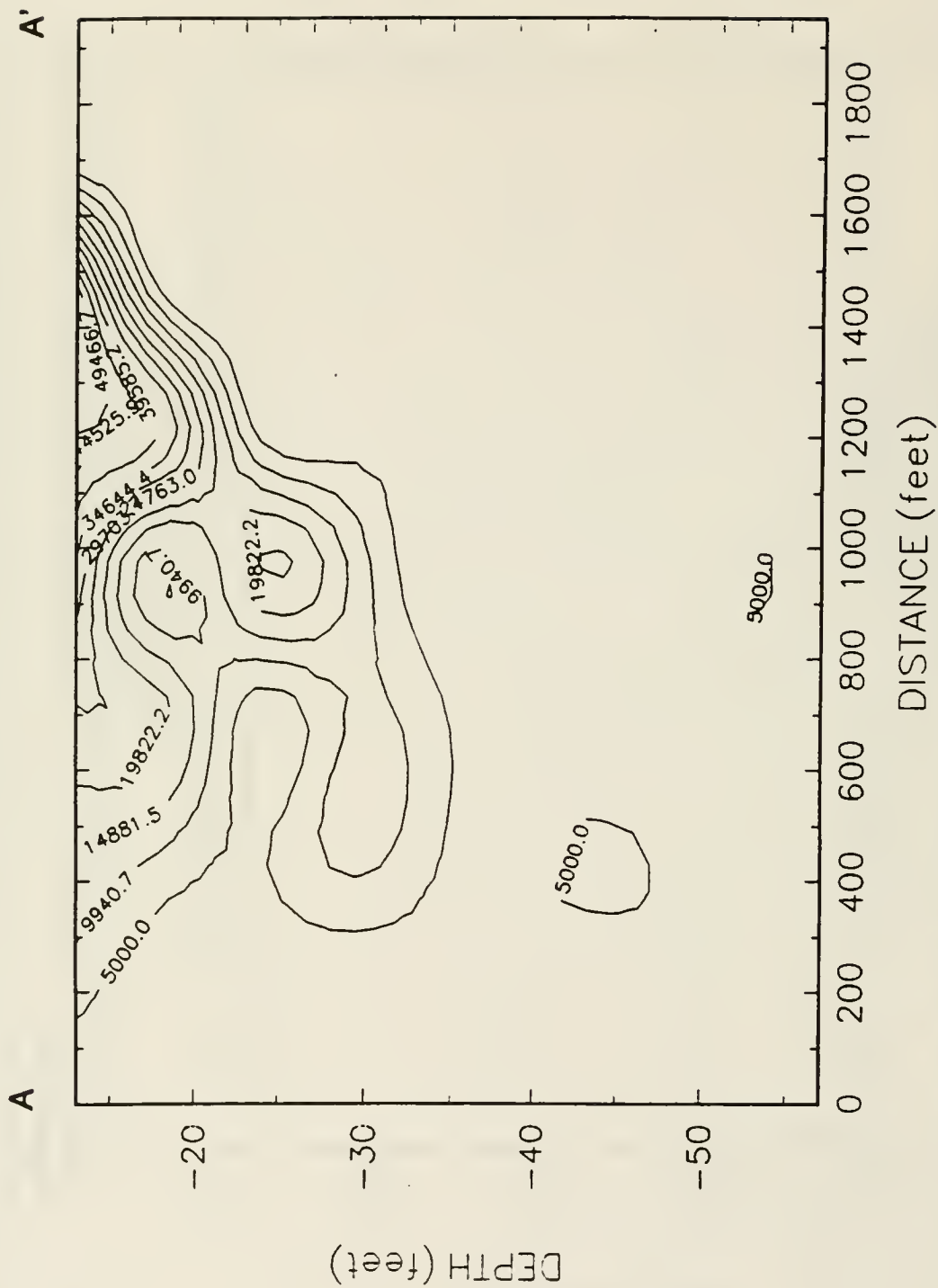


Figure 3-14C. Cross-Sectional Isopleth Map for Area I East of Montana Street: Zinc ($\mu\text{g/l}$), A-A'. Source: Appendix IIIA.

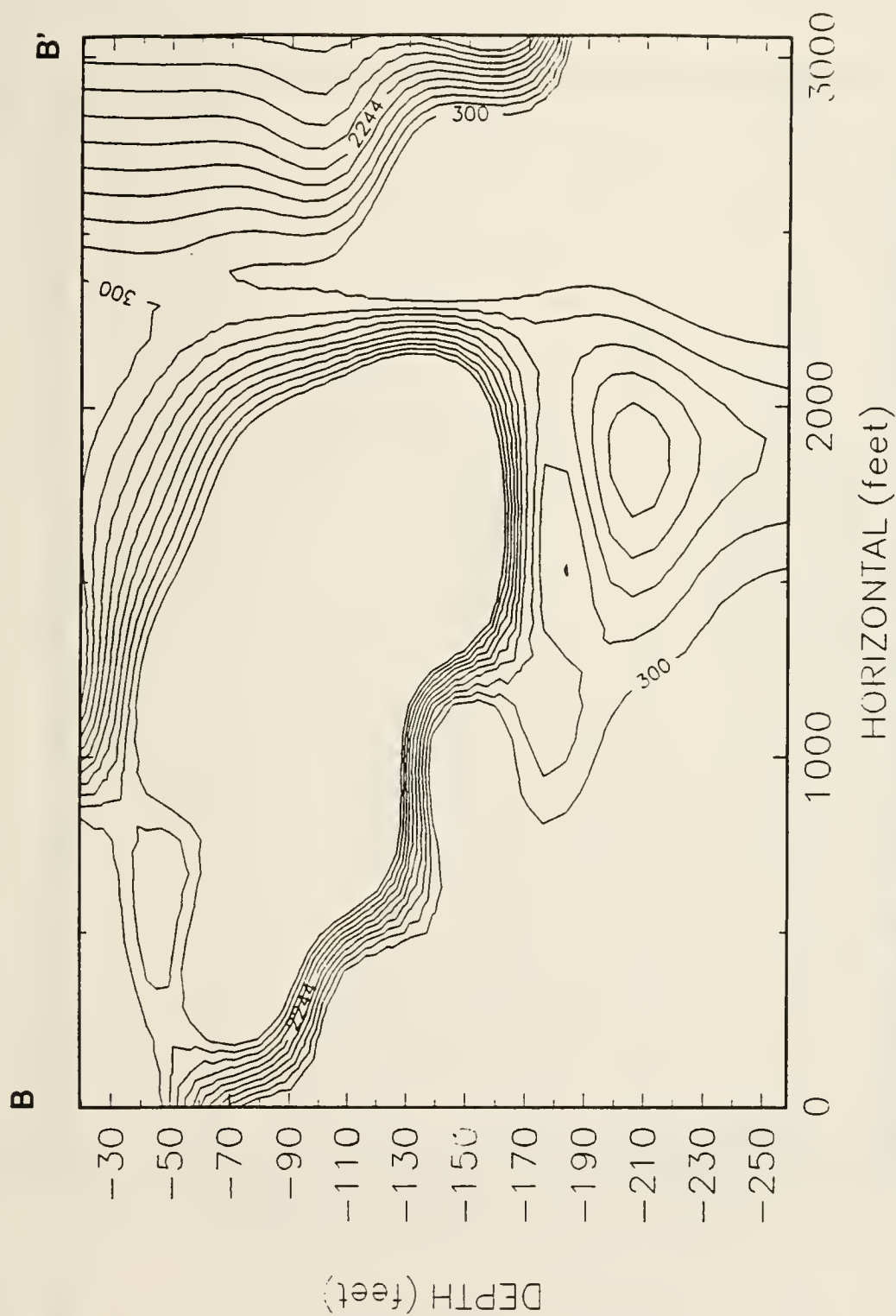


Figure 3-14D. Cross-Sectional Isopleth Map for Area I East of Montana Street: Iron ($\mu\text{g/l}$), B-B'.
Source: Appendix IIIA.

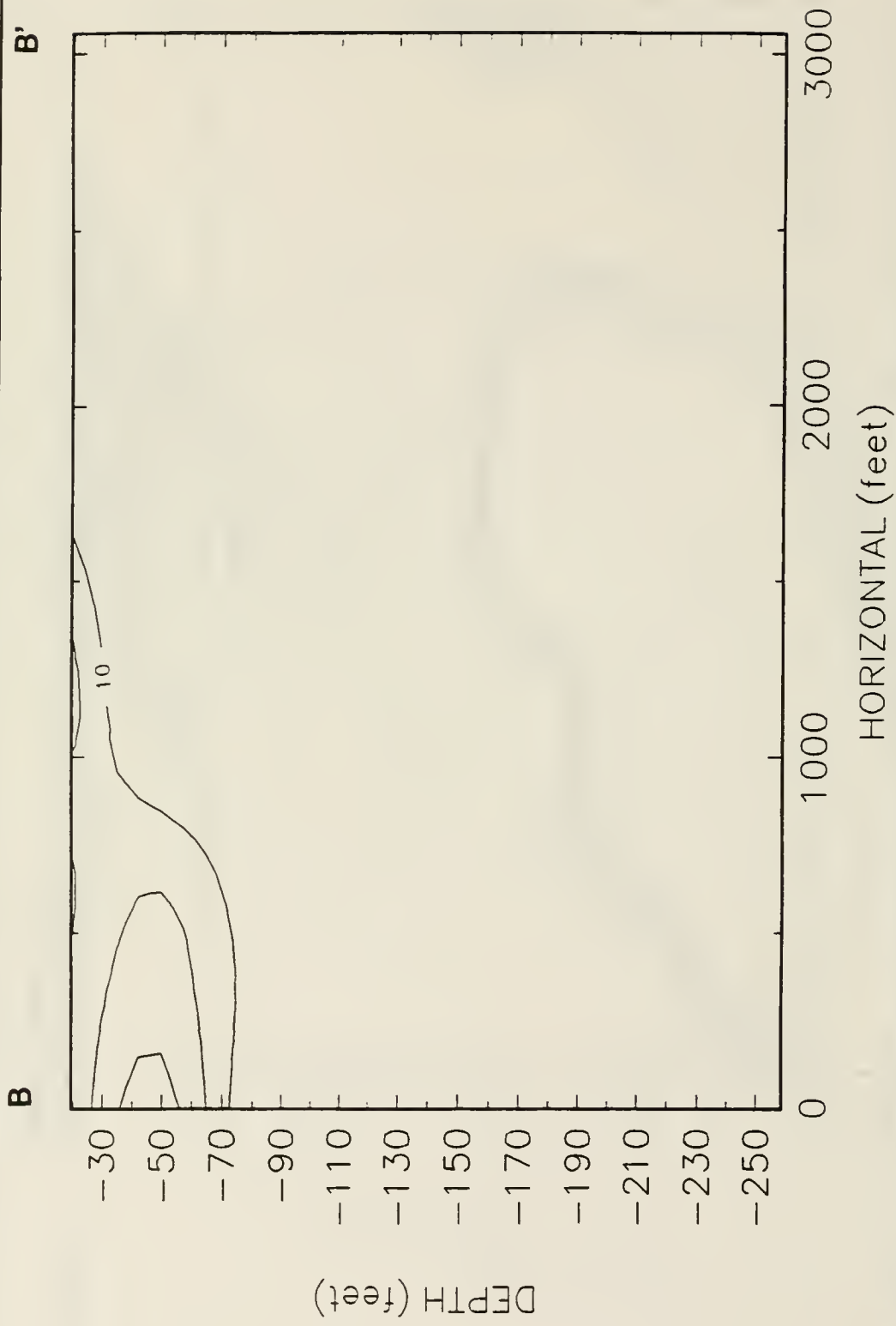


Figure 3-14E. Cross-Sectional Isopleth Map for Area I East of Montana Street: Lead ($\mu\text{g/l}$), B-B'. Source: Appendix IIIA.

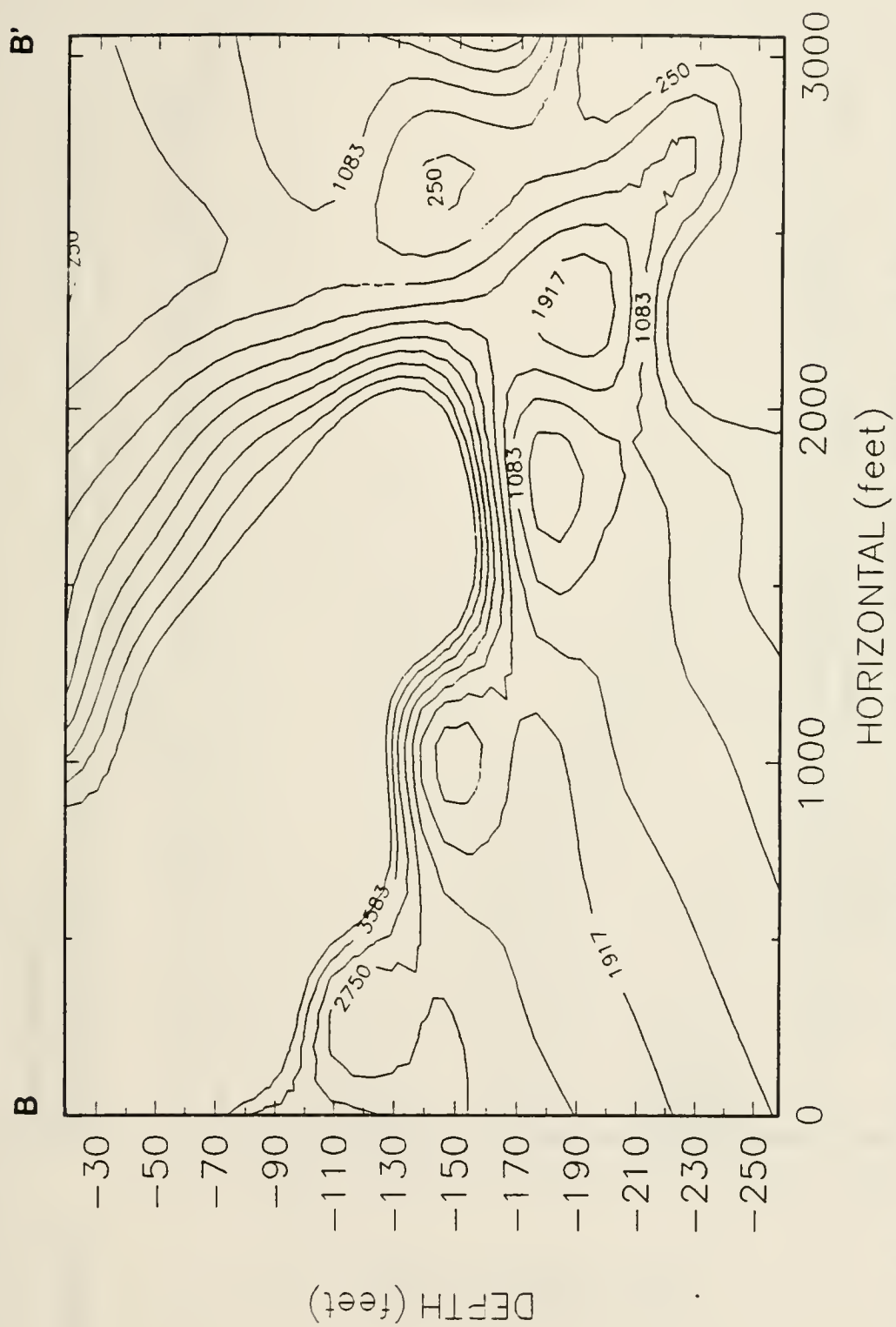


Figure 3-14F. Cross-Sectional Isopleth Map for Area I East of Montana Street: Sulfate (mg/l), B-B'.
Source: Appendix IIIA.

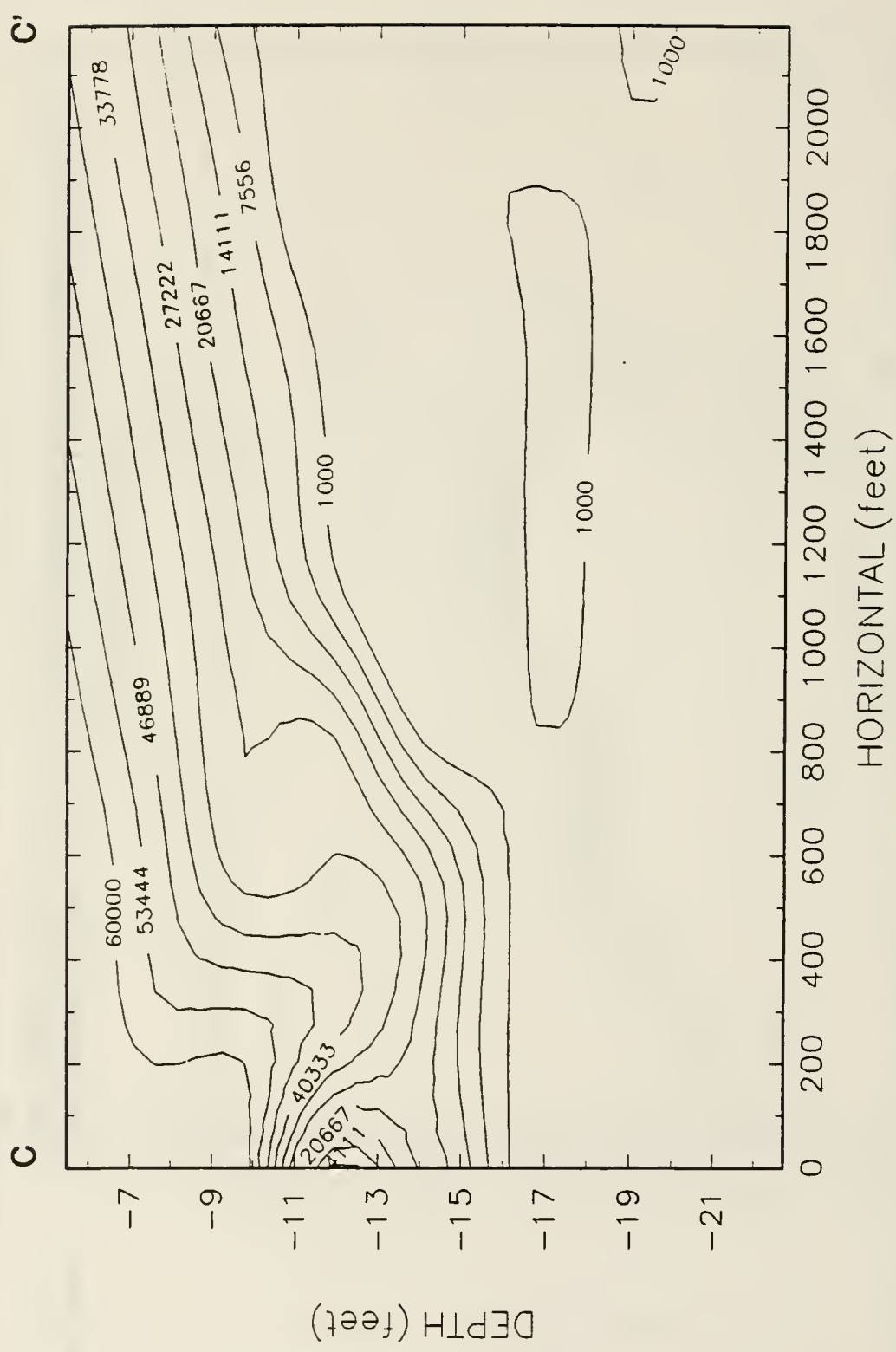


Figure 3-15A. Cross-Sectional Isopleth Map for Area I West of Montana Street: Copper (µg/l), C-C'.
Source: Appendix IIIA.

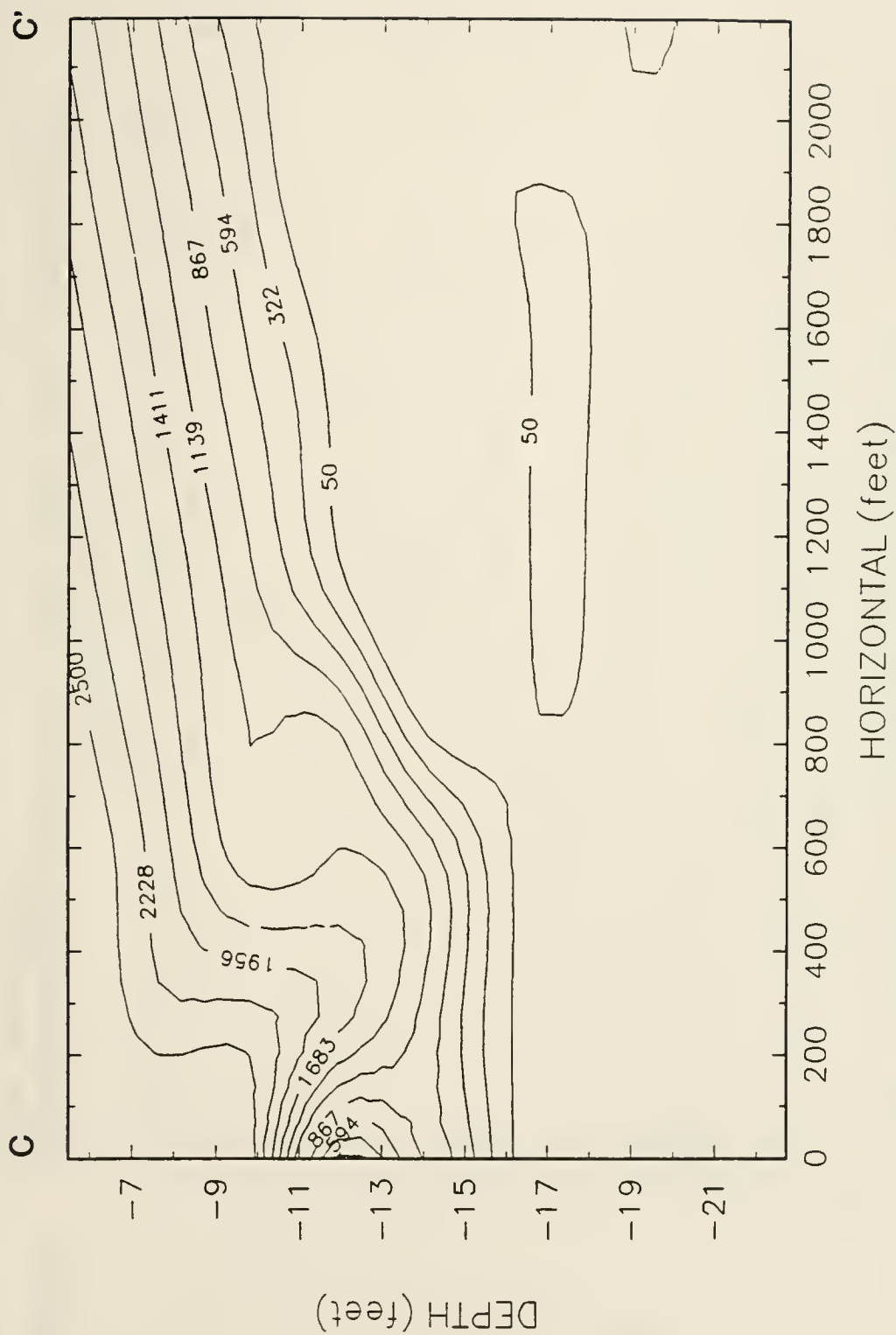


Figure 3-15B. Cross-Sectional Isopleth Map for Area I West of Montana Street: Lead ($\mu\text{g/l}$), C-C'.
Source: Appendix IIIA.

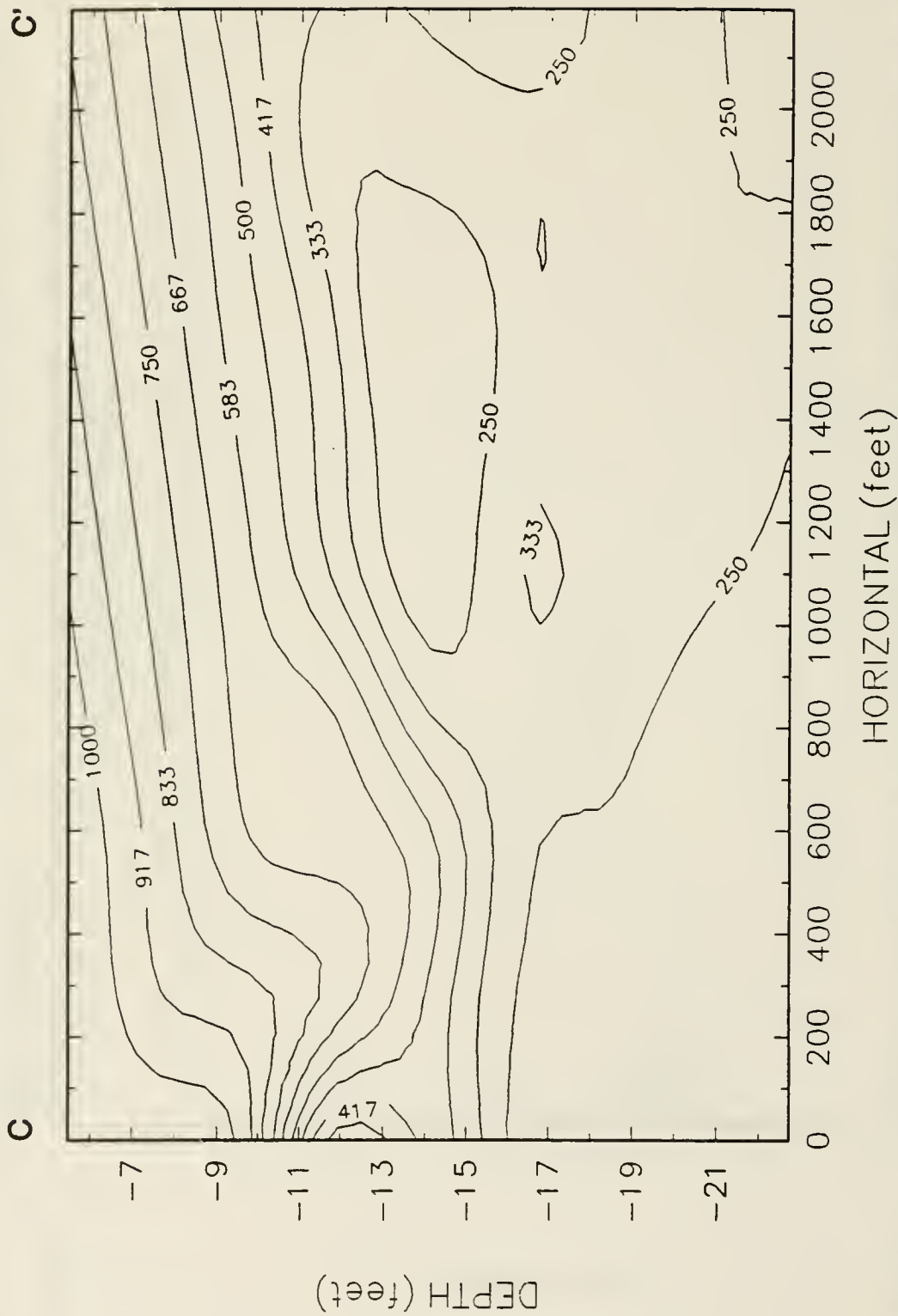


Figure 3-15C. Cross-Sectional Isopleth Map for Area I West of Montana Street: Sulfate (mg/l), C-C'.
Source: Appendix IIIA.

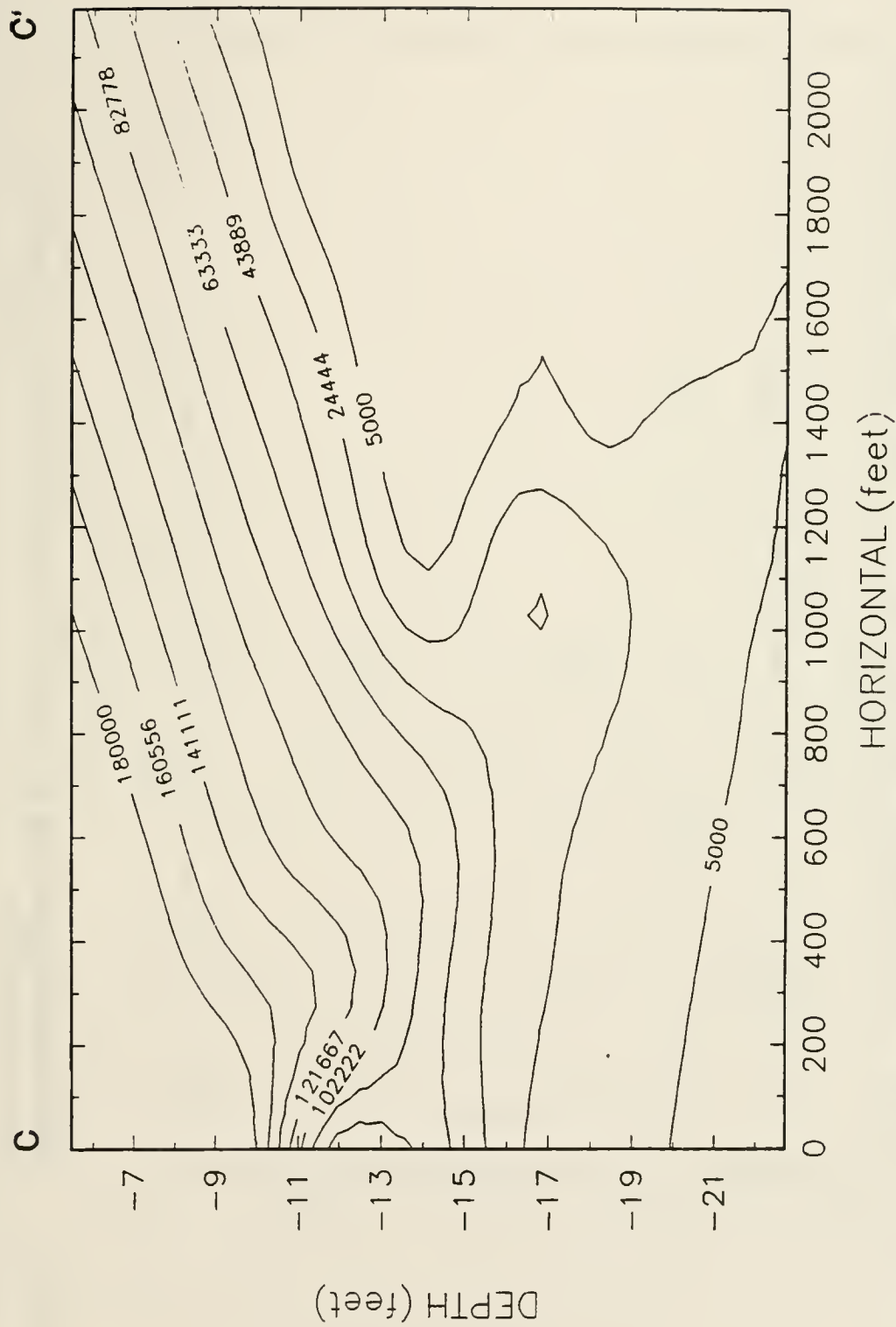


Figure 3-15D. Cross-Sectional Isopleth Map for Area I West of Montana Street: Zinc ($\mu\text{g/l}$), C-C'.
Source: Appendix IIIA.

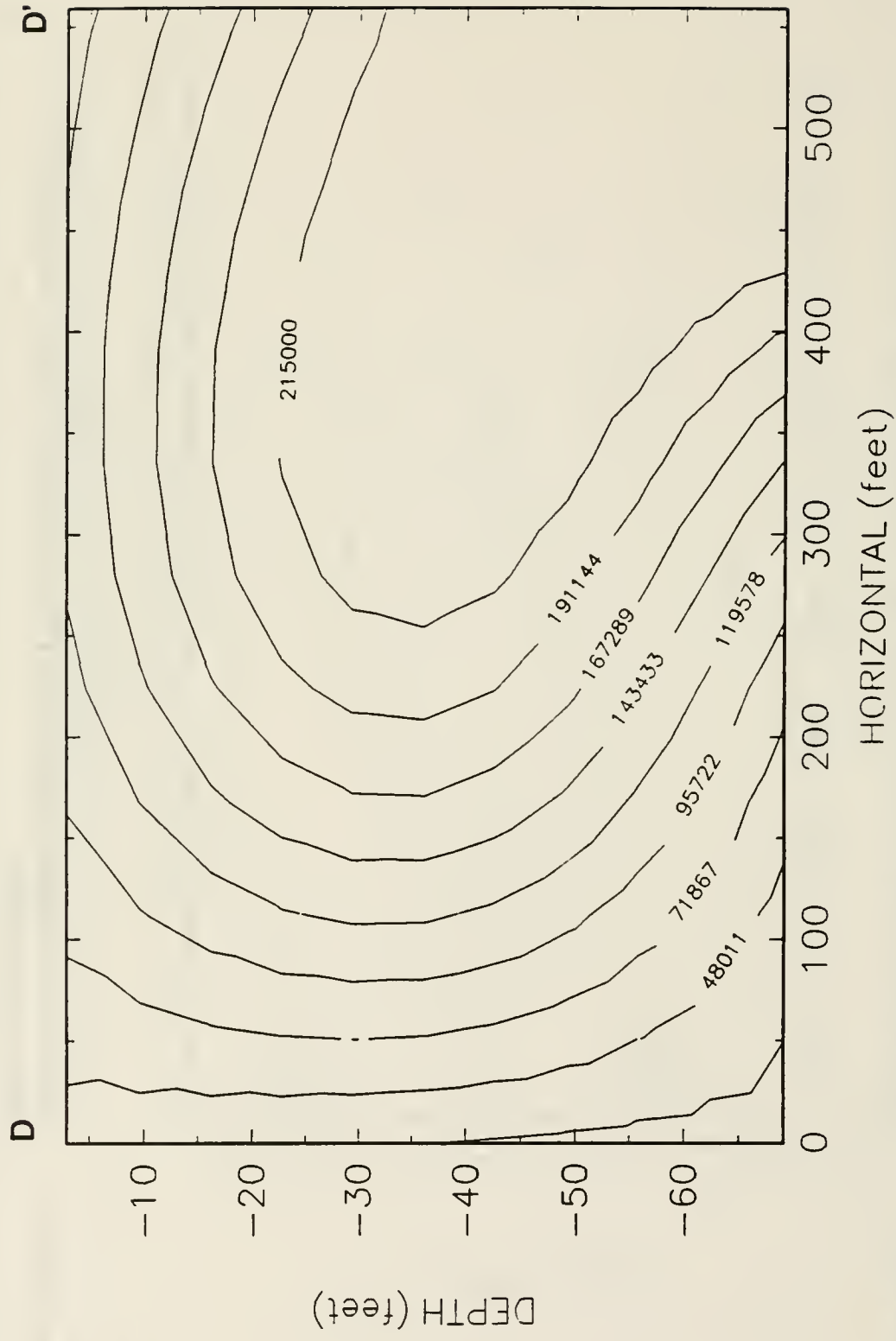


Figure 3-15E. Cross-Sectional Isopleth Map for Area I West of Montana Street: Iron ($\mu\text{g/l}$), D-D'.
Source: Appendix IIIA.

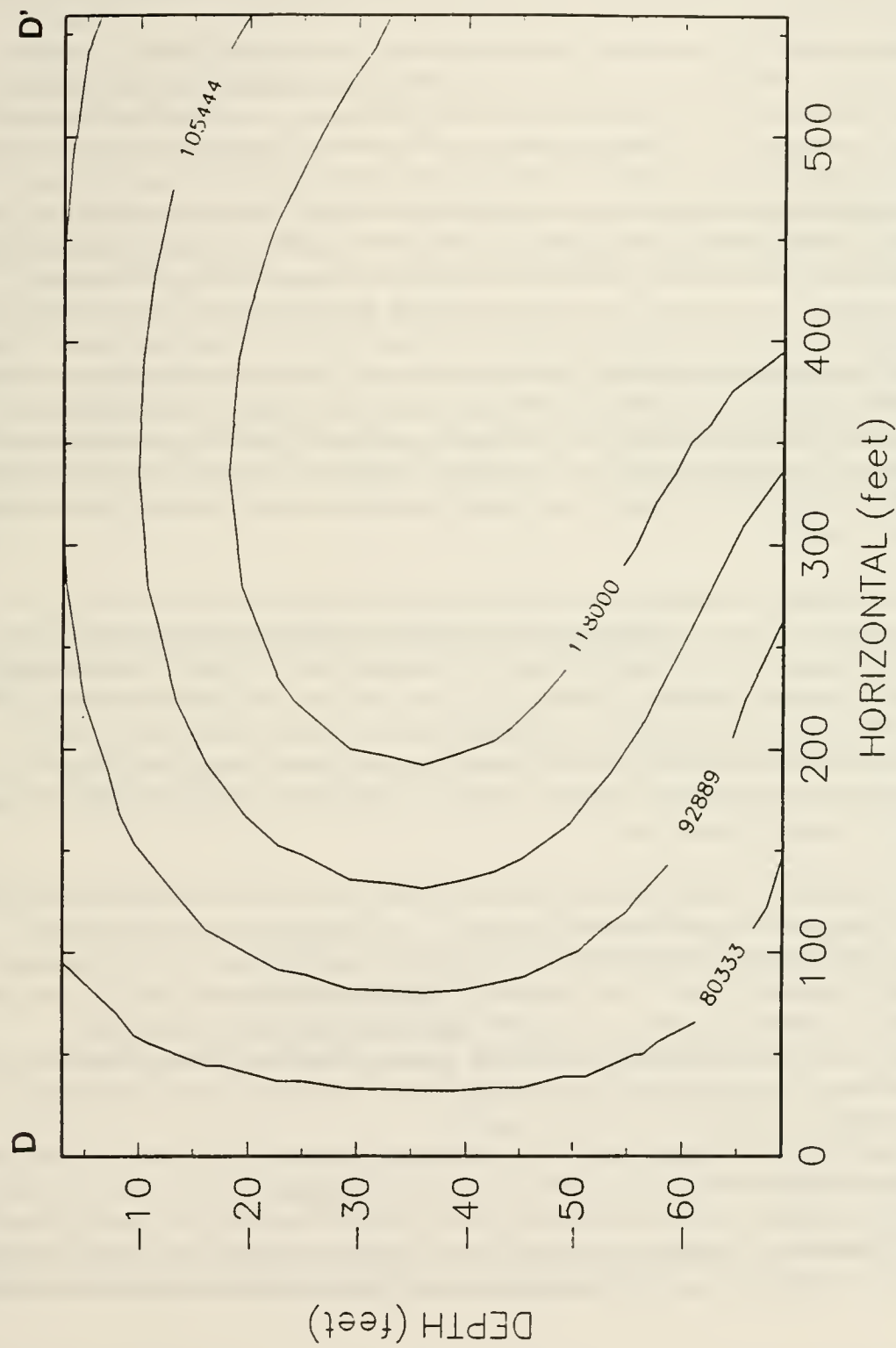


Figure 3-15F. Cross-Sectional Isopleth Map for Area I West of Montana Street: Zinc ($\mu\text{g/l}$), D-D'.
Source: Appendix IIIA.

The isopleth maps are to be used to assess the impact of known sources of hazardous substances on the location of groundwater plumes and to approximate the depth and extent of injured groundwater in Area I. Variations in lithologies and hydraulic conductivities, etc., between wells and lack of data make it impossible to use these isopleth maps in a strictly quantitative manner. However, in general the cross-sectional isopleth maps correspond well with groundwater flow patterns. In the Metro Storm Drain area, concentrations decrease with depth, which corresponds to a shallow source and a downward component of groundwater flow. Cross-section A-A' and B-B' are located in groundwater recharge areas, although B-B' can be in a groundwater discharge area, especially when stream flows are lower in the summer months. Conversely, in the Colorado Tailings area, D-D' is located in a groundwater discharge area and, as would be expected, concentrations increase with depth, indicating upward groundwater flow through a source of hazardous substances. C-C' is also located in a groundwater discharge area, especially during low stream flow in the summer months. The C-C' isopleth maps clearly show the old Silver Bow Creek channel, which was located closer to well GS-16 along this cross section. Contours curve around under the old Silver Bow Creek channel on the left side of the C-C' isopleth maps (near C), and concentrations in the isopleth maps do increase with depth in this vicinity. Similar groundwater flow patterns that follow or outline the old Silver Bow Creek channel are found in the Colorado Tailings area (Duaime et al., 1985).

The volume of injured groundwater in the Area I alluvial aquifer was estimated using the areal extent from the plan-view isopleth maps and the average depth of the groundwater plumes from the cross-sectional isopleth maps. The average depth of injury was estimated by first estimating the total area then to determine, by trial and error, the depth at which one-half of the total area lied above and below a horizontal line. For cross-section D-D' (west of Montana Street), if concentrations from the isopleth maps indicated a depth of injury exceeding the approximate alluvial-bedrock contact, a conservative depth of 65 feet was used for the depth of injured groundwater.

Some wells completed in bedrock in the Colorado Tailings areas do have concentrations of hazardous substances that exceed relevant standards. The surface area (in ft²), depth and volume of injured alluvial groundwater in Area I are presented in Table 3-13 for the areas west and east of Montana Street. Total volume of injured alluvial groundwater in Area I is also presented. A porosity of 20% was used for calculating the volume of injured groundwater for each hazardous substance. If the volumes of injured groundwater for areas both west and east of Montana Street are combined, the volume of hazardous substance groundwater plumes decreases in the following order:

sulfate > cadmium > zinc > iron > copper > lead > arsenic.

The largest plume was the sulfate plume, which had a volume of 4.34×10^8 cubic feet (9,960 acre-feet or 3.25 billion gallons). The cadmium plume was the second largest plume and had

a volume of 3.69×10^8 cubic feet. The composite of all plumes is larger than the sulfate plume and is shown in Figure 3-12.

3.2.3 Flux or Yield of Injured Groundwater

3.2.3.1 Yield of Injured Bedrock Aquifer Groundwater

In order to maintain water levels below mine workings, bedrock groundwater was pumped from the Kelley Mine at the rate of 5,000 to 8,000 gallons per minute (CDM/FPC, 1990). Piper (1960) described the "pumping capacity" of the mines as 8,000 gpm with "frequent flows" of 6,900 gpm for periods of up to 90 minutes.

The flow required to maintain water levels below mine workings represents the yield of injured groundwater associated with the underground mine workings during the period of underground mining. Groundwater within the volume of influence of the mines would be intercepted by mine workings and become injured with sulfate and metals. The yield of the injured bedrock groundwater is estimated at 6,900 gpm or 1,300,000 ft³/yr or 11,100 acre-feet/yr.

3.2.3.2 Flux of Injured Alluvial Aquifer Groundwater

3.2.3.2.1 Butte Hill

Flux calculation were based on a flow-net constructed from potentiometric data presented in Canonie (1992a) and Darcy's Law:

$$Q = n \cdot T \cdot CI,$$

where

n	=	Number of flow tubes within the areal extent of the contamination
T	=	Transmissivity (ft ² /day)
CI	=	Contour interval or hydraulic gradient.

A flow net is constructed by plotting streamlines, which are parallel to groundwater flow, and equipotential lines, which are perpendicular to groundwater flow. The streamlines and equipotential lines are spaced so that they are all equal in width and length (the flow net is composed of "squares"). The result is a flow net in which a flow tube is formed by adjacent streamlines. Discharge is equal throughout any one flow tube.

The transmissivity value used was that reported in Canonie (1992a). Flux values were calculated for cadmium, copper, iron, lead, sulfate, and zinc and are presented in Table 3-12. The average flux of injured alluvial groundwater in the Butte Hill area is given by the flux of the largest plumes, zinc, sulfate, cadmium, and copper, which are 17,900 ft³/day (150 acre-ft/yr). This represents flux through the central portion of the Butte Hill alluvial aquifer.

3.2.3.2.2 Area I

The Colorado Tailings is located in a groundwater discharge area, as described in earlier sections. Fractured bedrock is close to the surface at the west end of the Colorado Tailings, and this area has a thin layer of alluvium compared to areas east of the Colorado Tailings. Consequently, the majority of groundwater in Lower Area I exits the Butte Basin as surface water at the west end of the Colorado Tailings. The total discharge to Silver Bow Creek at the west end of the tailings, however, includes surface water from within the basin. Surface water inflows include Blacktail Creek, Metro Storm Drain, Missoula Gulch and the Metro Sewer Treatment Plant (MSTP).

The net groundwater discharge was calculated by subtracting each of the surface water inflows from the total discharge of Silver Bow Creek at the west end of the Colorado Tailings. The result is a net groundwater discharge leaving the Butte Basin as surface water. The net groundwater flow calculated by this method underestimates the total groundwater discharge from the basin, because the groundwater discharging as groundwater through the alluvium and bedrock are not accounted for. Data were not available to calculate a bedrock aquifer discharge; however, a groundwater discharge was estimated for the alluvial aquifer based on data presented in CH₂M Hill and Chen-Northern (1990).

Surface water discharge data were obtained for Blacktail Creek and Silver Bow Creek from USGS gaging stations, for Metro Storm Drain and Missoula Gulch from the USGS (MBMG, 1994), and for the Metro Sewerage Treatment Plant from USGS personnel and directly from MSTP personnel. Attachment II presents data from the USGS gaging station in Blacktail Creek at Butte and in Silver Bow Creek below Blacktail Creek at Butte, and data on flows in the MSD and Missoula Gulch from April and November, 1990 from the USGS.

Groundwater flow was calculated using long term averages of annual flows, where available. The data are summarized in Table 3-15. A better method would be to use a groundwater flow model with input data from pump tests in alluvial aquifer and better flow estimates on Missoula Gulch and MSD; however, the data for such a method were not currently available. The surface water inflows from Blacktail Creek, the Metro Storm Drain and the Metro Sewerage Treatment Plant were subtracted from the gaging station below the Colorado Tailings. The net groundwater discharge as surface water for the basin is 3.25 cfs.

Flux of injured groundwater was determined based on a flow net constructed from potentiometric data presented in CH₂M Hill and Chen-Northern (1990) and Darcy's Law (as described above) and is presented in Table 3-13. Transmissivity values used were those reported in CH₂M Hill and Chen-Northern (1990). Lack of transmissivity data precluded estimating a flux for the cross-section A-A'. Groundwater exiting the basin via alluvium was calculated based on the discharge through the alluvium near the west end of the Colorado Tailings (Section D-D') and is estimated as 0.053 cfs (4,550 ft³/d or 38.1 acre-ft/yr) (Table 3-13). The net groundwater discharge exiting the Butte Basin is estimated as the sum of the alluvial aquifer discharge (0.053 cfs) and the net surface water discharge (3.25 cfs) (Table 3-15), or 3.30 cfs (1,480 gpm or 2,390 acre-ft/year or 104,000,000 ft³/yr).

Summary information on areal extent, volumetric extent and flux of injured groundwater in the study area is presented in Table 3-16.

Table 3-15
Mean Flow Data for Area I Surface Waters

	Mean (cfs)	Basis
Blacktail Creek above MSD	10.2	Mean annual flow, water years 1989-93; USGS
Metro Storm Drain	0.30	Mean of two measurements (4/12/90 & 11/8/90) USGS
Missoula Gulch	0.74	Mean of two measurements (4/12/90 & 11/8/90) USGS
Metro Sewerage Treatment Plant	7.21	Mean of five years (1988-1992) MSTP pers. comm.
Silver Bow Creek below Colorado Tailings	21.7	Mean annual flow, water years 1984-93; USGS
Net Flow: Silver Bow Creek - Colorado Tailings =		3.25 cfs 1,459 gpm 2,353 acre-ft/yr
Source: Attachment II.		

Table 3-16
Summary of Areal and Volumetric Extent and Flux of Injured Groundwater in Area I and Butte Mine Flooding Operable Units

Aquifer Type and Location	Areal Extent	Volumetric Extent	Flux or Yield
Bedrock Butte Hill	2.01 × 10 ⁸ ft ² 7.22 mi ² 4,620 acres	1.43 × 10 ¹⁰ ft ³ 327,000 ac-ft 107 billion gallons	6,900 gpm 1,330,000 ft ³ /yr 11,100 ac-ft/yr
Alluvial Area I	2.45 × 10 ⁷ ft ² 0.88 mi ² 563 acres	4.34 × 10 ⁸ ft ³ 9,960 ac-ft 3.25 billion gallons	1,480 gpm 104,000,000 ft ³ /yr 2,390 ac-ft/yr
Alluvial Butte Hill	2.20 × 10 ⁷ ft ² 0.79 mi ² 505 acres	2.12 × 10 ⁸ ft ³ 4,850 ac-ft 1.59 billion gallons	17,900 ft ³ /yr 150 ac-ft/yr
Total	2.48 × 10 ⁸ ft ² 8.89 mi ² 5,690 acres	1.50 × 10 ¹⁰ ft ³ 342,000 ac-ft 112 billion gallons	105,000,000 ft ³ /yr 13,600 ac-ft/yr

4.0 RECOVERABILITY

Recoverability is defined in this report as the time estimated for the groundwater resource to recover to baseline concentration levels if no additional remediation or restoration efforts are taken. The groundwater in the alluvial and bedrock aquifers is contaminated with inorganic hazardous substances — metals, metalloids, and sulfate — which generally are not capable of being biologically degraded or transformed into less toxic or mobile species. Potential immobilization and mobilization mechanisms that may affect the extent of contaminated groundwater over time are discussed below.

4.1 POTENTIAL IMMOBILIZATION MECHANISMS

Several of the metalloids — arsenic, selenium and antimony — can be transformed to methylated species by bacteria and/or fungi. Methylated arsenic and antimony are less toxic than their inorganic counterparts, but they are still dissolved species and would remain in affected groundwaters.

Sulfate can also be reduced to elemental sulfur or sulfide by microbes. Sulfide can complex with a number of metals and metalloids to form relatively insoluble (under reducing conditions) solid sulfides. Elemental sulfur and sulfide minerals could be immobilized in sediments, aquifer materials or the Berkeley Pit under sufficiently reducing conditions. Unfortunately, dissolved sulfide was not determined in any study area groundwaters or in the pit water. It appears that the redox state of large portions of the groundwater and pit water is relatively reducing, judging from the mobility of iron and manganese and the pH range. However, even though reduced iron and manganese are present, there must not be sufficiently reducing conditions to generate significant quantities of sulfide, which could immobilize metals and metalloids by formation of sulfide minerals.

Minewater quality in a few of the shafts has been improving over time to some extent (Ted Duaime, personal communication; Appendix II), and this may be due to increased reducing conditions, the formation of sulfide and the precipitation of metal/metalloid sulfides in the minewaters. In contrast, the quality of the pit water appears to be worsening with time (Ted Duaime, personal communication; Appendix I), perhaps as a result of increased time for reaction of the pit walls with enclosed pit water under mildly reducing conditions. At present, geochemical conditions in the Berkeley Pit are not capable of immobilizing contaminants by precipitation of sulfide minerals.

4.2 POTENTIAL ENLARGEMENT OF PLUME

Maximum transport rates for several groundwater contaminants were estimated in an earlier section using plan-view isopleth maps from CH₂M Hill and Chen-Northern (1990) and assuming that the year 1900 was the mid-point of source application:

Sulfate	=	72.7 ft/yr
Zinc	=	63.6 ft/yr
Copper	=	62.5 ft/yr
Cadmium	=	61.4 ft/yr
Iron	=	45.5 ft/yr
Arsenic	=	19.9 ft/yr
Lead	=	14.2 ft/yr.

The ordering of transport rates would be somewhat different if the plan-view isopleth maps presented in this report (Chapter 3.0) were used. In addition, as discussed earlier, the rate of transport would be more rapid if a more recent data was used as the mid-point of application of minewater discharge to the MSD and Silver Bow Creek. It was also found that this ordering of decreasing transport rates roughly corresponded to decreasing volume of groundwater plumes contaminated with hazardous substances in the alluvial aquifer in Area I:

sulfate > cadmium > zinc > iron > copper > lead > arsenic.

Assuming that the sources hazardous substances to groundwater will not be removed, these and other contaminants can be expected to be transported at similar estimated maximum transport rates in the future and thereby increase the size of hazardous substance plumes, especially in the upper MSD area. In Lower Area One, groundwater discharge to Silver Bow Creek limits the lateral extent of groundwater contamination, but the extent of contamination with depth may increase over time.

Sulfide minerals in the primary sources of hazardous substances in the study area can be expected to leach lesser quantities of metals, metalloids and sulfate to the unsaturated zone and groundwater over time as hazardous and related substances are exhausted by leaching mechanisms. This scenario depends on a number of geochemical and hydrodynamic factors including consistent or overall oxidizing conditions in the source materials (buried tailings, etc.) and availability of infiltrated water, sufficient hydraulic conductivities, etc. The oxidation of pyrite in mine wastes has been modeled, assuming that the oxidation rate is limited by the rate of oxygen supplied to pyrite. Oxygen supply was assumed to be by diffusion through pore space in the wastes followed by diffusion into a moving reaction front within the particles (Davis et al., 1986; Davis and Ritchie, 1986). The production of sulfate from pyrite in mine wastes was predicted to decrease exponentially in the first 50 to 100 years but not approach zero sulfate production until between 250 to over 350 years from the

time of deposition of the wastes (Figure 4-1). If reducing conditions are generated periodically over time as a result of rising water levels in the alluvial aquifer, for example, this process of exhaustion of hazardous and related materials by leaching will be interrupted and slowed. Any reclamation attempts to reduce the oxidation of pyritic waste materials (i.e., capping) without preventing migration of hazardous substances to groundwater (i.e., by use of a liner system) will eventually reduce the rate of acid formation but extend the time frame of groundwater injury.

It can be assumed that sources of hazardous substances in the study area will continue to adversely affect alluvial and bedrock groundwater and Berkeley Pit water for thousands to tens of thousands of years absent removal of the sources or implementation of effective *in situ* remediation or restoration techniques (Tetra Tech, 1986).

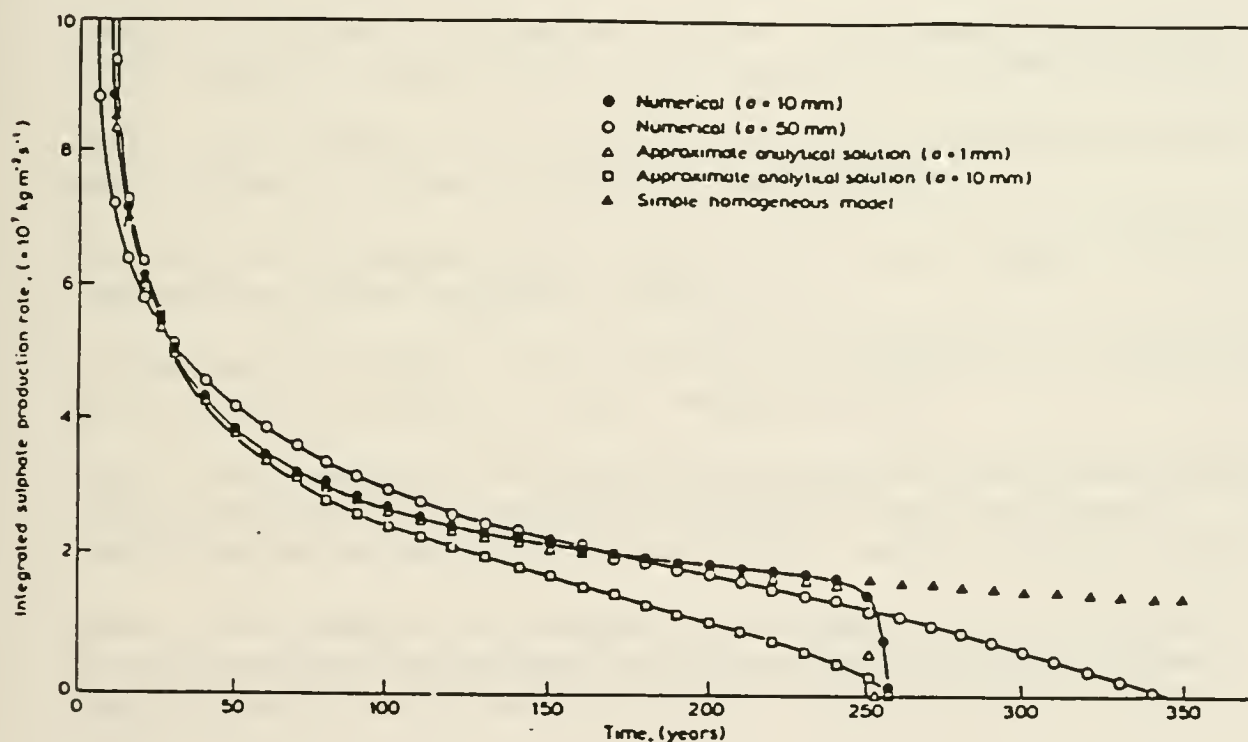


Figure 4-1. Total Sulfate Production Rate as a Function of Time After Creation of Wastes. Source: Davis and Ritchie, 1986.

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ATTACHMENT I

**TESTING AND SAMPLING METHODS FOR NRDA BEDROCK AND ALLUVIAL
AQUIFER SAMPLES**

1.0 TESTING AND SAMPLING METHODS FOR NRDA BEDROCK AND ALLUVIAL AQUIFER SAMPLES

1.1 BEDROCK GROUNDWATER SAMPLING

1.1.1 Bedrock Sampling Locations

Bedrock water quality samples were collected from one mine shaft, four bedrock monitoring wells and one municipal well (Hebgen) as part of the Natural Resource Damage Assessment (NRDA) investigation. Sampling locations are shown on Plate I. Analytical results from these samples are provided in Appendix IIC. The Marget Ann mine shaft is located in Walkerville, north of the city of Butte, and Hebgen Park, the municipal well, is located approximately three-quarters of a mile southwest of the Berkeley Pit. Bedrock monitoring wells B, E, D1 and D2 are located within Montana Resources, Inc. (MRI) property and were installed as part of the Butte Mine Flooding Remedial Investigation/Feasibility Study (RI/FS). The Hebgen Park well, Marget Ann shaft, wells B and D1 were sampled in April 1992, and wells D2 and E were sampled in May 1992. Table AI-1 provides information on the well depth, screened interval, and static water level at the time of sampling for each of the locations. Wells A and C, included in this table, were also installed as part of the Butte Mine Flooding RI/FS. Although they were not sampled for the NRDA investigation, data obtained from previous sampling episodes are included in this report. The analytical results for the NRDA bedrock water quality investigation are displayed in Appendix II-C.

1.1.2 Bedrock Groundwater Collection Methods

Field procedures followed during this investigation are described in the Sampling and Analysis Plan for the Butte Hill Investigation (MBMG, 1992) and the Clark Fork River

Superfund Site Investigations Standard Operating Procedures (CFRSSISOP) (ARCO, 1992). Static water level was measured before purging and sampling at each location (CFRSSISOP GW-5). The pH meter was calibrated before use at each well according to CFRSSISOP HG-8. The accuracy of the Eh meter was checked according to CFRSSISOP HG-8. The specific conductivity meter was calibrated according to CFRSSISOP HG-7. Sample bottles were precleaned according to CFRSSISOP HG-3.1. Documentation of field activities conformed to CFRSSISOP G-4. Field equipment was decontaminated according to CFRSSISOP G-8. Deviation from this SOP occurred when the inside of the pump was not flushed with distilled water. Groundwater samples were collected using a stainless steel submersible pump attached to a discharge hose or pipe. The wells and mine shaft were purged until specific conductivity, temperature, pH and Eh stabilized to $\pm 10\%$ for three consecutive readings. A minimum of three casing volumes was removed from each well.

Table AI-1
Bedrock Sampling Location Information

Location	Well/Shaft Depth (ft)	Screen Interval (ft)	TOC Elevation (ft)	Depth to Water	Water Elevation (ft)
Hebgen	300	140-300	5,526.5	31.86	5,494.64
Marget Ann	600	None	NA	119.08	
Well A	745	680-700 720-740	5,524.98	NS	
Well B	640	568-578	5,557.82	317.44	5,240.38
Well C	800	755-795	5,577.98	NS	
Well D1	635	600-620 620-630	5,591.54	560.13	5,031.41
Well D2	775	660-670 720-740 760-770	5,579.51	548.93*	5,030.58
Well E	355	270-290 320-350	5,562.45	170.58	5,391.87
NA = Not Available. NS = Not Sampled for NRDA Investigation. TOC = Top of Casing Elevation. * = D2 Depth to water taken on 5/01/92. Depth to water = Static water level prior to sampling well.					

1.1.3 Sample Handling and Preservation

Two sets of samples were collected at each location. One set of samples was signed over to ARCO oversight personnel using chain of custody forms. The following set of samples was collected:

- ▶ 1 500-ml filtered, preserved with 5 ml of nitric acid (pH < 2)
- ▶ 1 500-ml unfiltered, unpreserved (raw)
- ▶ 1 250-ml filtered, unpreserved.

Preservation and holding times were described in the Sampling and Analysis Plan for the Butte Hill Investigation (MBMG, 1992).

1.1.4 Analytical Protocols Applied to the Bedrock Groundwater Analysis

The suite of samples was submitted to the Montana Bureau of Mines and Geology Analytical Division laboratory in polyethylene bottles. A field sheet (MBMG Form 173) containing information about each sample, the requested analyses, and chain of custody documentation accompanied each set of bottles. A separate chain of custody document (U.S. EPA R8 014B) accompanied the submittals from each sampling event. The samples were logged into the laboratory and given a laboratory identification number. The sample storage area of the MBMG Analytical Division is a locked, restricted access area within the main office. When samples were removed from the area for analysis, a custody logbook was maintained.

The raw unpreserved samples were analyzed for specific conductance, pH, and alkalinity immediately upon receipt at the laboratory. The filtered unpreserved samples were analyzed for F, Cl, Br, NO₃-N, OPO₄-P, and SO₄ within 28 days of log-in. The filtered acidified samples were analyzed for the dissolved major cations and trace metals. Table AI-2 identifies the appropriate U.S. EPA Methods for the parameters.

Table AI-2 Analytical Methods Employed by MBMG for NRDA Groundwater Samples		
Parameter	Bottle Type	U.S. EPA Method
Ca, Mg, Na, K, Fe, Ag, Al, B, Cr, Ni, P, Sr, Ti, V, Zr	FA	200.7
SiO ₂	FU	200.7
As, Cd, Cu, Mn, Mo, Pb, Zn	FA	200.8
Alkalinity	RU	310.1
Specific Conductance	RU	120.1
pH	RU	150.1
F	FU	340.2
Cl, Br, NO ₃ -N, OPO ₄ -P, SO ₄	FU	300.0A
FA = Filtered, Acidified. FU = Filtered, Unpreserved. RU = Raw, Unpreserved.		

For the critical elements, spikes and duplicates were included at a 10% frequency; Initial and Continuing Calibration Standards from different sources were included at the appropriate intervals. A Laboratory Control Sample from the USGS Standard Reference Waters was included with every run.

The required demonstration of instrument performance for both ICP-AES (for Fe) and ICP-MS (for As, Cd, Cu Mn, Mo, Pb, Zn) was carried out before the analysis of samples. The data produced for these elements have been validated. MBMG Analytical Division Quality Assurance guidelines were followed in determining the remaining analytes. These guidelines also require spiking and duplication of samples at 10% frequency and the analysis of control samples. The cation-anion balance is an additional quality assurance parameter imposed on the analysis of dissolved constituents. The parameter a(2), which assesses the lack of agreement in the balance must be within ± 1 ; otherwise the sample is reanalyzed for suspect analytes. If balance is not achieved after reanalysis, the data are flagged.

1.2 ALLUVIAL GROUNDWATER SAMPLING

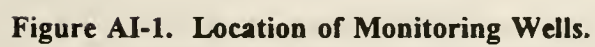
1.2.1 Alluvial Sampling Locations and Monitoring Well Installations

The location of the alluvial aquifer baseline monitoring wells (AW1, AW2, AW3) is shown in Figure AI-1. These wells were drilled into alluvium underlain by the Butte Quartz Monzonite, the host rock to the ore deposits in Butte. The wells are upgradient from known mining activities. The analytical results for the NRDA alluvial aquifer baseline monitoring wells are presented in Appendix III-D.

The three monitoring wells were drilled using the MBMG's Mobile B-50 drill rig and the hollow stem auger drilling method (ARCO, 1992, Clark Fork River Superfund Site Investigations Standard Operating Procedure (CFRSSISOP) GW-3). Prior to drilling each bore hole, the hollow stem augers were rinsed with water to remove any soil and/or sediment, thus preventing cross contamination between sites (CFRSSISOP G-8).

Each well was drilled in two stages. During the first stage, a hole was drilled using 3.25-inch inside diameter (ID) hollow stem augers. A split sampler was used during this stage of the drilling, and where possible, continuous samples were collected. The split sampler was decontaminated each time it was removed from the hole, after collecting the sample (CFRSSISOP G-8).

The split sampler was advanced with the auger flights as the hole was drilled. In some cases, the split sampler would encounter a rock that would prevent the auger flights from advancing. In these cases, the split sampler was removed from the hole to allow the auger flights to advance past the rock, and hence continuous samples were not collected. The samples were placed on a piece of plastic and logged lithologically. Lithologic logs for the wells are included in the following pages. After logging the hole, the samples were bagged and are on file at the MBMG. Samples from the screened intervals from the three wells were submitted to the analytical lab at the MBMG for analysis. The 3.25-inch ID hollow stem auger bore hole was drilled until presumably bedrock was encountered — the depth at which the augers would not advance any farther. The monitoring well construction information and schematics specific to each site are provided in Table AI-3.



Remarks Collected water sample. LAB Number 9201433 Drilled with 3.25 in ID Hollow Stem Augers
to 23'. Reamed this hole with 6.0 in. ID Hollow stem augers to 18'

[illegible]

WELL LOG

MONTANA BUREAU OF MINES AND GEOLOGY

County Silver Bow Location: T. 03N R. 07W Sec. 15 Twp 00DB Hole name or number AW7

Hole location West of I-15 and South of Old Columbia Gardens Guard House

Recorded by J. Madison Date hole started 9/24/92 Date hole completed 9/24/92 Driller F. Schmidt Drilling company MEMG

+2-15 - 4" PVC Casing 15-20-4" 0.020" Screen

Total well depth (ft.) 20 ft. Well diameter(s) +2-4-6" Steel protective casing

Type of casing(s): A. Steel (black) C. Plastic E. Wood cribbing Weight or gauge of casing _____ Method - perforated or screened: _____
B. Steel (gal.) D. Open hole F. Other (specify) _____

Interval - perforated _____
or screened: 15'-20' 0.020 Slotted PVC Sch 80

Has or will well be test pumped? Yes No Were material samples taken? Yes No Was a water sample(s) taken? Yes No

Remarks 3.25" ID Hollow stem auger hole was drilled to 29'. Reamed 6" ID Hollow stem auger to 20'. Water quality analysis 9201435 on file at MEMG.

DRILLING LOG			Estimated composition, %							
From	To	Geological, drilling, and water conditions; remarks and sampling	Gravel		Sand		Silt		clay	
			c	f	w	c	m	f		v
0"	8"	Black low density organic rich horizon.								
8"	1.2'	Greyish brown horizon. Low moisture content. Core is crumbly.								
		Material is mostly silt and clay. Small % of clast are 2-5 mm diameter. Clast are quartz and unweathered country rock.								
1.2'	1.9'	Similar to 8" - 1.2' zone. This zone is darker than 8" - 1.2' zone.								
1.2'	2.1'	Boulder upon which soil above 1.9' formed on. Consists of Q-Monzonite. Most of Biotite has been weathered/altered. Rock is grey with some Fe(OH) ₃ staining.								
2.1'	4'	Coarse grain alluvium. Composed of clast of feldspar, mica, quartz and Q-monzonite. Clast are very angular. Some clast, which are Q-monzonite, are up to 1 cm in diameter. Very wet.								
4'	4.8"	Same as 2.1'-4'. Only difference is contains some clay which makes the sample sticky.								
4.8'	5.4'	Fine grain. Mostly clay and silt. Buff color. Contains organic rich (black) stringers. Gold mica is present.								
5.4'	12'	Coarse grain. Clast of quartz, feldspar, Q-Monzonite, and mica. Not much clay - Core is crumbly. Gold color mica. Grey. Clasts are angular.								
12.'	12.2	Organic rich layer. Roots and twigs chocolate color.								
12.2	13'	Coarse grain. Clay makes core sticky. Clast are quartz, feldspar, and mica. Poorly sorted. Fe(OH) ₃ Stains on clast.								
13'	14'	Coarse grain. Fragments of unaltered Q-Monzonite up to 4cm diameter. Angular clast.								
14'	16'	No sample. Had to remove sampler from hole to advance past rock								
16'	19'	Coarse grain. Buff color. Clast up to 2 cm diameter but mostly								

Remarks _____

[illegible]

Table AI-3
Monitoring Well Construction

[All values are distances below land surface in feet except those preceded by + which are distances above land surface]

Well	Total Depth of 3.25" ID Hollow Stem Auger Hole	Total Depth of 6.00" ID Hollow Stem Auger Hole	Cased Interval	Screened Interval	Sand Packed Interval	Grouted Interval	Protective Casing Interval
AW1	23	18.5	+2-13	13-18	11-18	0-11	+2.3-4
AW2	29	20	+2-15	15-20	14-20	12-14, 0-5	+2.3-4
AW3	32	28	+2.4-23	23-28	22-28	0-22	+2.7-2

During the second stage, the 3.25-inch ID hollow stem auger pilot hole was reamed using 6.0-inch ID hollow stem augers. To prevent the 6.0-inch ID hollow stem augers from filling with cuttings, a tapered wooden plug was hammered into the bottom of the lead auger. After drilling to the desired depth, an iron rod about 3 feet long and 1.25 inches in diameter attached to a rope was dropped inside the hollow stem augers to knock the wooden plug out.

After the wooden plug was knocked out, 5 feet of 4-inch PVC Triloc 0.020" slotted screen and the desired length of 4-inch PVC triloc casing were screwed together and placed in the augers (See Table AI-3). The augers were pulled out of the hole in 1- to 2-foot increments, and filter pack that consisted of 10-20 Colorado silica sand was placed in the annular space adjacent to the screen. The top of the filter pack was at least one foot above the top of the screen (Figures AI-2, AI-3, and AI-4).

Once the filter pack was in place, a bentonite slurry was poured into the augers, and the augers were pulled out of the hole. The bentonite slurry consisted of 0.25-inch bentonite crumbles, liquid polymer (Ultra-Vis), and tap water from Montana Tech. The well annulus was filled with the bentonite slurry from the top of the sand pack to land surface at most of the sites (See Figures AI-2, AI-3, and AI-4) (CFRSSISOP GW-10).

The top of the casing of all wells was at least 2 feet above land surface. A 6-inch steel protective casing was placed around all wells. The protective casing extended from a few inches above the top of the well casing to a minimum of about 2 feet below land surface. A 3 feet × 3 feet × 6 inch concrete apron was poured around the protective casing. The wells were secured with locking protective caps that were installed on the protective casings (CFRSSISOP GW-10).

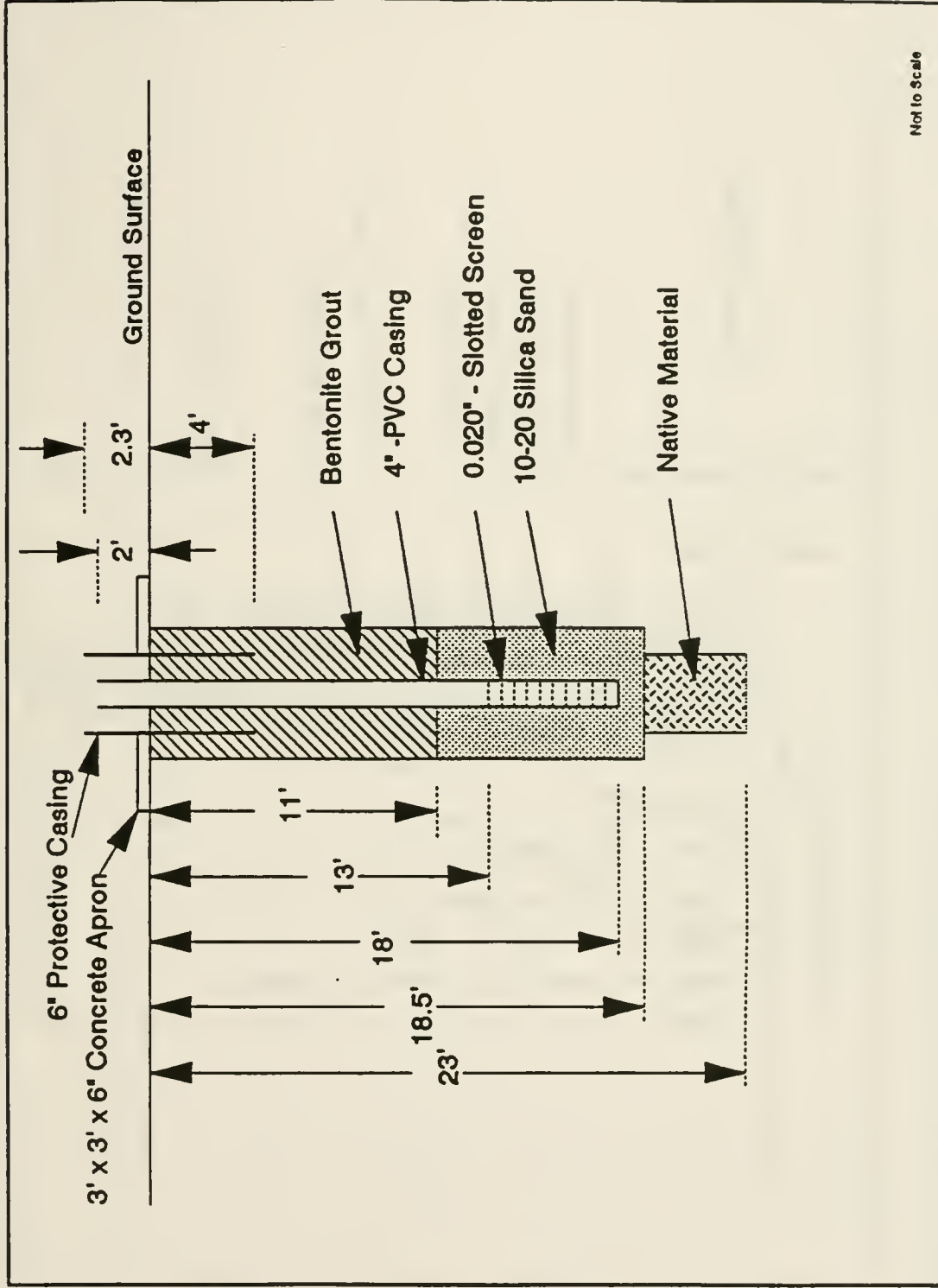


Figure AI-2. Schematic of Monitoring Well AW1.
RCG/Hagler Bailly

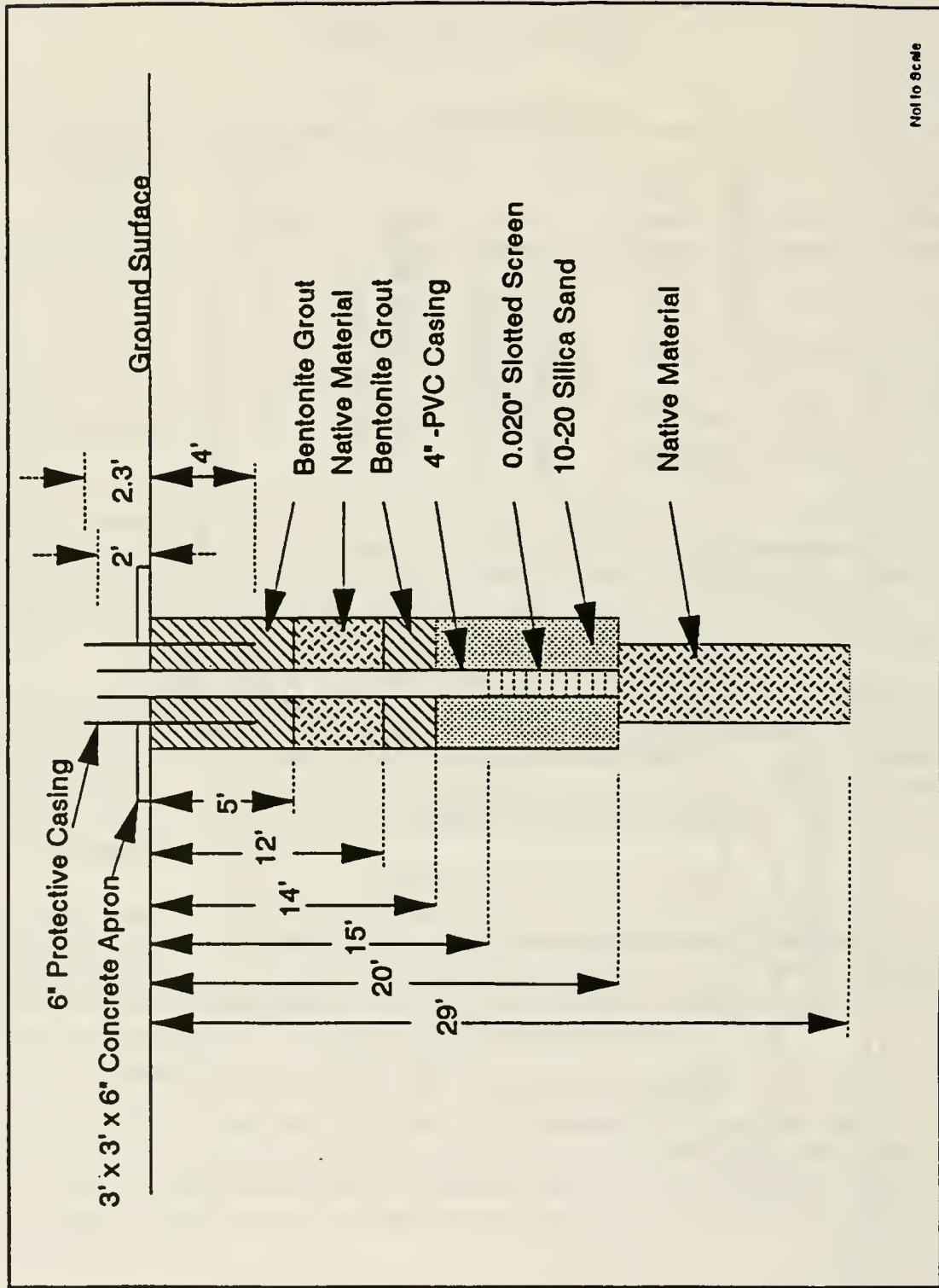


Figure AI-3. Schematic of Monitoring Well AW2.

RCC/Hagler Bailly

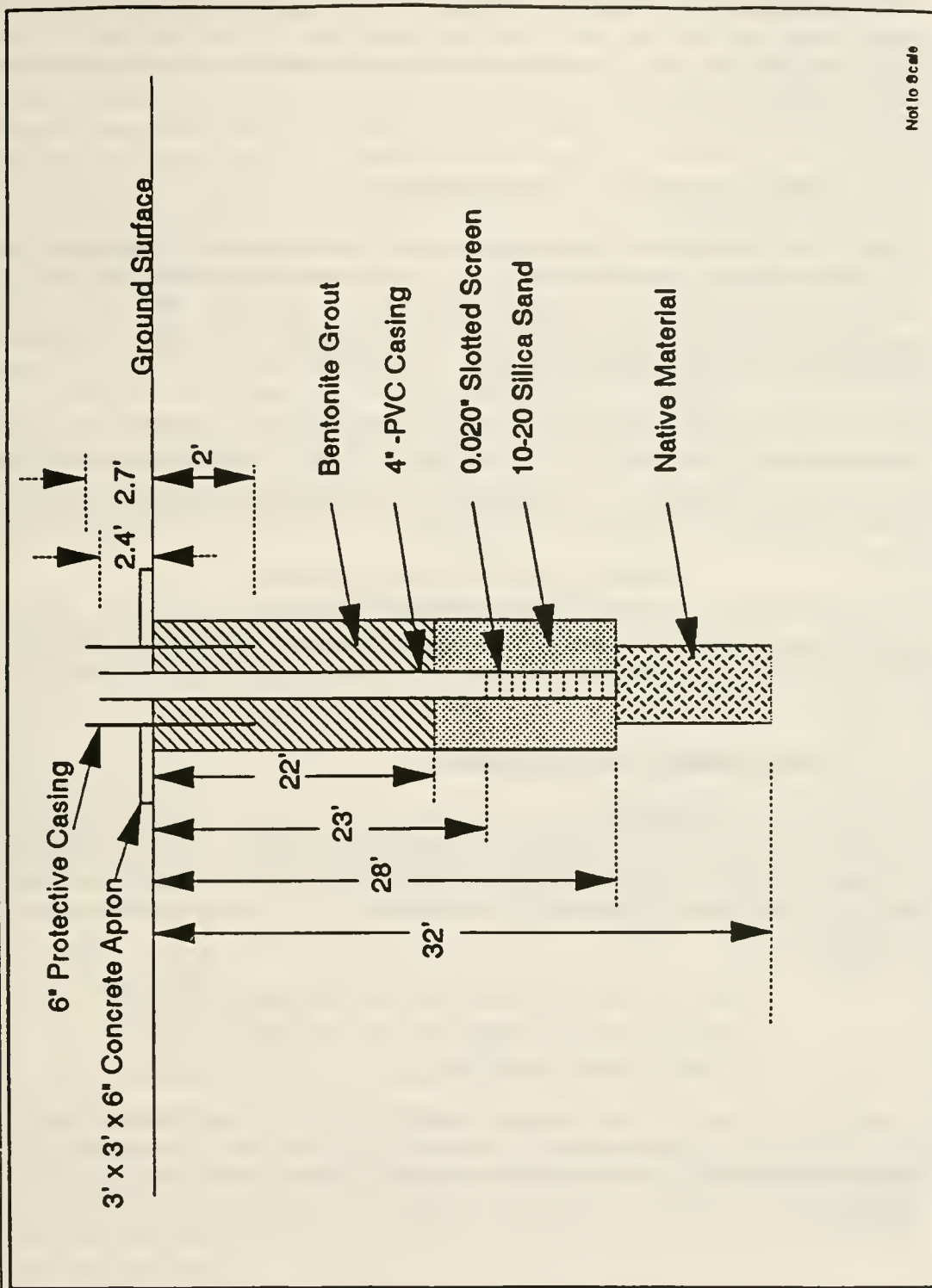


Figure AI-4. Schematic of Monitoring Well AW3.

RCG/Hagler Bailly

All of the wells were developed by surging and pumping (CFRSSISOP GW-4). The wells were pumped until the water was visually sediment free. However, pumping the wells after they had recovered always resulted in turbid water that would become visually sediment free after pumping for some period of time.

1.2.2 Alluvial Groundwater Collection Methods

Groundwater samples were collected using a stainless steel submersible pump attached to a flexible discharge hose (CFRSSISOP GW-1). Static water levels were measured at each site prior to purging using a decontaminated electric tape (CFRSSISOP GW-5). The wells were purged until a minimum of three casing volumes was removed, and specific conductivity, temperature, and pH stabilized within 10% (CFRSSISOP GW-1).

Prior to sampling each site, the pump, the hose, and any other equipment used to sample were decontaminated (CFRSSISOP G-8). The decontamination procedure consisted of circulating dilute nitric acid solution through the pump and hose for about 10 minutes. The nitric acid rinse was followed by flushing about 10 gallons of deionized water through the pump and hose.

Samples that required filtering were filtered using 0.45 μ m disposable filters. The filter was attached to a connection on the end of the pump hose using a short piece of disposable tygon tubing. The filter and hose were disposed of after collecting sample from each site.

1.2.3 Sample Handling and Preservation

Two sets of groundwater samples were collected at each location. One set of samples was signed over to ARCO oversight personnel using chain of custody forms. The other set of samples was signed over to the MBMG laboratory using chain of custody forms and MBMG laboratory forms (CFRSSISOP G-7). The following set of groundwater samples was collected at each site:

- ▶ 1 500-ml filtered, preserved with 5 ml of nitric acid (pH < 2)
- ▶ 1 500-ml unfiltered, unpreserved (raw)
- ▶ 1 250-ml filtered, unpreserved.

In addition to the groundwater samples collected at the three sites, Quality Assurance/Quality Control (QA/QC) samples were also collected (CFRSSISOP G-6). The set of QA/QC samples consisted of a rinseate blank, a filter blank, a bottle blank, a duplicate, and two trip blanks.

1.2.4 Analytical Protocols Applied to the Analysis of Alluvial Groundwater Samples

The suite of samples was submitted to the Montana Bureau of Mines and Geology Analytical Division laboratory in polyethylene bottles. A field sheet (MBMG Form 173) containing information about each sample, the requested analyses, and chain of custody documentation accompanied each set of bottles. A separate chain of custody document (U.S. EPA R8 014B) accompanied the submittals from each sampling event. The samples were logged into the laboratory and given a laboratory identification number. The sample storage area of the MBMG Analytical Division is a locked, restricted access area within the main office. When samples were removed from the area for analysis, a custody logbook was maintained.

The raw unpreserved bottles were analyzed for specific conductance, pH, and alkalinity immediately upon receiving the samples. The filtered unpreserved bottles were analyzed for F, Cl, Br, NO₃-N, OPO₄-P, and SO₄ within twenty-eight days of log-in. The filtered acidified samples were analyzed for the dissolved major cations and trace metals. Table AI-4 identifies the appropriate U.S. EPA Methods for the parameters.

Table AI-4
Analytical Methods Employed by MBMG
for NRDA Groundwater Samples

Parameter	Bottle Type	U.S. EPA Method
Ca, Mg, Na, K, Fe, Ag, Al, B, Cr, Ni, P, Sr, Ti, V, Zr	FA	200.7
SiO ₂	FU	200.7
As, Cd, Cu, Mn, Mo, Pb, Zn	FA	200.8
Alkalinity	RU	310.1
Specific Conductance	RU	120.1
pH	RU	150.1
F	FU	340.2
Cl, Br, NO ₃ -N, OPO ₄ -P, SO ₄	FU	300.0A
FA = Filtered, Acidified.		
FU = Filtered, Unpreserved.		
RU = Raw, Unpreserved.		

For the critical elements, spikes and duplicates were included at a 10% frequency; Initial and Continuing Calibration Standards from different sources were included at the appropriate intervals. A Laboratory Control Sample from the USGS Standard Reference Waters was included with every run.

The required demonstration of instrument performance for both ICP-AES (for Fe) and ICP-MS (for As, Cd, Cu, Mn, Mo, Pb, Zn) was carried out prior to the analysis of samples. The data produced for these elements have been validated. MBMG Analytical Division Quality Assurance guidelines were followed in determining the remaining analytes. These guidelines also require spiking and duplication of samples at 10% frequency and the analysis of control samples. The cation-anion balance is an additional quality assurance parameter imposed on the analysis of dissolved constituents. The parameter $\sigma(2)$, which assesses the lack of agreement in the balance, must be within ± 1 ; otherwise the sample is reanalyzed for suspect analytes. If balance is not achieved after reanalysis, the data are flagged.

ATTACHMENT II

**INFORMATION USED TO CALCULATE FLUX
OF
INJURED ALLUVIAL GROUNDWATER IN AREA I**

STATION NUMBER 12323240 BLACKTAIL CREEK AT BUTTE STREAM SOURCE AGENCY USGS
 LATITUDE 455438 LONGITUDE 1123138 DRAINAGE AREA 95.4 DATUM STATE 30 COUNTY 093

DISCHARGE, CUBIC FEET PER SECOND
 DAILY MEAN VALUES

	1989 OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL	279.8	281.1	284.0	242.0	199.4	450.4	525	527	354.8	266.5	349.8	318.0
MEAN	9.03	9.37	8.55	7.81	7.12	14.5	17.5	17.0	11.8	8.60	11.3	10.6
MAX	14	12	10	8.0	7.9	46	29	23	16	12	17	21
MIN	8.1	8.9	7.8	7.5	6.5	7.0	11	13	8.9	6.9	8.8	9.3
AC-FT	555	558	525	480	396	893	1040	1050	704	529	694	631
WTR	YR 1989	TOTAL 4058.7	MEAN 11.1	MAX 46	MIN 6.5	AC-FT 8050						

	1990 OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL	355	293.5	287.3	302.4	259.5	315.5	422	415	391.3	261.1	288.2	254.6
MEAN	11.5	9.78	9.27	9.75	9.27	10.2	14.1	13.4	13.0	8.42	9.23	8.49
MAX	13	10	9.7	14	12	13	19	27	18	12	14	11
MIN	10	8.8	9.0	8.8	8.5	8.8	12	10	8.7	6.8	6.7	7.5
AC-FT	704	582	570	600	515	626	837	823	776	518	568	505
CAL	YR 1989	TOTAL 4168.7	MEAN 11.4	MAX 46	MIN 6.5	AC-FT 8270						
WTR	YR 1990	TOTAL 3843.4	MEAN 10.5	MAX 27	MIN 6.7	AC-FT 7620						

	1991 OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL	269.0	275.2	237.1	243.3	227.1	230.1	327.8	576.7	523	244.0	284.9	261.5
MEAN	8.68	9.17	7.65	7.85	8.11	7.42	10.9	18.7	17.4	7.87	9.19	8.72
MAX	11	11	8.5	9.0	8.6	8.2	14	31	30	12	17	13
MIN	7.8	8.5	6.0	7.0	7.8	6.5	8.2	9.5	12	6.6	7.8	6.8
AC-FT	534	546	470	483	450	456	650	1150	1040	484	565	519
CAL	YR 1990	TOTAL 3688.6	MEAN 10.1	MAX 27	MIN 6.0	AC-FT 7320						
WTR	YR 1991	TOTAL 3701.5	MEAN 10.1	MAX 31	MIN 6.0	AC-FT 7340						

	1992 OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL	253.3	280.8	260.3	250.9	243.6	333.9	280.9	226.7	298.2	254.2	207.8	179.4
MEAN	8.17	9.36	8.40	8.09	8.40	10.8	9.36	7.31	9.94	8.20	6.70	5.98
MAX	9.5	12	10	8.8	11	13	11	11	24	15	11	7.9
MIN	7.5	7.9	7.7	7.8	7.4	9.7	7.4	5.8	6.3	6.0	5.5	4.4
AC-FT	502	557	516	498	483	662	557	450	591	504	412	356
CAL	YR 1991	TOTAL 3714.8	MEAN 10.2	MAX 31	MIN 6.5	AC-FT 7370						
WTR	YR 1992	TOTAL 3070.0	MEAN 8.39	MAX 24	MIN 4.4	AC-FT 6090						

	1992 OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL	253.3	280.8	260.3	250.9	243.6	333.9	280.9	226.7	298.2	254.2	207.8	179.4
MEAN	8.17	9.36	8.40	8.09	8.40	10.8	9.36	7.31	9.94	8.20	6.70	5.98
MAX	9.5	12	10	8.8	11	13	11	11	24	15	11	7.9

	1993 OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL	253.4	233.6	243.8	215.8	177.3	364.9	349	374.9	510	427.1	489.8	288.1
MEAN	8.17	7.79	7.86	6.96	6.33	11.8	11.6	12.1	17.0	13.8	15.2	9.60
MAX	19	8.3	8.5	7.5	6.8	20	15	24	48	26	42	13
MIN	6.9	7.4	7.1	6.5	5.8	6.2	10	7.7	10	9.2	6.2	8.2
AC-FT	503	483	484	428	352	724	692	744	1010	847	932	571
CAL	YR 1992	TOTAL 3006.4	MEAN 8.21	MAX 24	MIN 4.4	AC-FT 5960						
WTR	YR 1993	TOTAL 3907.7	MEAN 10.7	MAX 48	MIN 5.8	AC-FT 7750						

	1994 OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL	352.3	---	254.5	234.7	---	---	561	566	312.4	349.0	197.4	---
MEAN	11.4	---	8.21	7.57	---	---	18.7	18.3	10.4	11.3	6.37	---
MAX	15	---	9.0	8.0	---	---	31	30	14	68	8.3	---
MIN	8.4	---	7.4	7.1	---	---	12	13	5.9	6.0	5.3	---
AC-FT	899	---	505	466	---	---	1110	1120	620	692	392	---

	1995 OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL	270.6	255.6	---	---	---	---	---	---	---	---	---	---
MEAN	8.73	8.52	---	---	---	---	---	---	---	---	---	---
MAX	12	13	---	---	---	---	---	---	---	---	---	---
MIN	6.6	7.7	---	---	---	---	---	---	---	---	---	---
AC-FT	537	507	---	---	---	---	---	---	---	---	---	---

CAL YR 1992 TOTAL 3006.4 MEAN 8.21 MAX 24 MIN 4.4 AC-FT 5960
 WTR YR 1993 TOTAL 3907.7 MEAN 10.7 MAX 48 MIN 5.8 AC-FT 7750

	1994 OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL	352.3	---	254.5	234.7	---	---	561	566	312.4	349.0	197.4	---
MEAN	11.4	---	8.21	7.57	---	---	18.7	18.3	10.4	11.3	6.37	---
MAX	15	---	9.0	8.0	---	---	31	30	14	68	8.3	---
MIN	8.4	---	7.4	7.1	---	---	12	13	5.9	6.0	5.3	---
AC-FT	899	---	505	466	---	---	1110	1120	620	692	392	---

STATION NUMBER 12323250 SILVER BOW CREEK BL BLACKTAIL CREEK AT BUTTE MT STREAM SOURCE AGENCY USGS
 LATITUDE 455949 LONGITUDE 1123343 DRAINAGE AREA 103.00 DATUM 5410.8 STATE 30 COUNTY 093

DISCHARGE, CUBIC FEET PER SECOND
 DAILY MEAN VALUES

	1984 OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL	828	772	702	705	637	798	1124	1361	1282	722	703	666
MEAN	26.7	25.7	22.6	25.6	22.0	25.7	37.5	43.9	42.7	23.3	22.7	22.2
MAX	33	28	24	48	23	32	59	72	89	36	35	26
MIN	23	23	21	21	21	21	27	32	26	21	20	21
AC-FT	1640	1530	1390	1580	1260	1580	2230	2700	2540	1430	1390	1320

	1985 OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL	748	722	659	623	536	737	1161	778	694	570	539	602
MEAN	24.1	24.1	21.3	20.1	19.1	23.8	38.7	25.1	23.1	18.4	17.4	20.1
MAX	27	27	23	22	20	29	100	43	59	38	34	52
MIN	23	22	20	19	18	20	23	19	16	16	14	14
AC-FT	1480	1430	1310	1240	1060	1460	2300	1540	1380	1130	1070	1190

	1986 OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL	622	509	486	488	682	873	761	965	750	569	606	704
MEAN	20.1	16.7	15.7	15.7	24.4	28.2	25.4	31.1	25.0	16.0	19.5	23.5
MAX	24	19	17	20	91	37	30	46	57	33	64	58
MIN	18	16	15	15	16	22	21	23	16	16	15	18
AC-FT	1230	992	964	968	1350	1730	1510	1610	1490	1170	1200	1400

	1987 OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL	597	579	494	529	514	871	929	1212	789	1056	859	686
MEAN	19.3	19.3	15.9	17.1	18.4	28.1	31.0	39.1	26.3	34.1	27.7	22.2
MAX	28	25	18	19	22	65	39	99	48	75	39	25
MIN	18	16	14	16	17	18	22	19	17	17	24	20
AC-FT	1180	1150	980	1050	1020	1730	1840	2400	1560	2090	1700	1320

	1988 OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL	677	606	556	532	538	686	1016	850	621	511	579	507
MEAN	21.8	20.2	17.9	17.2	18.6	22.1	33.9	27.4	20.7	16.5	18.7	16.9
MAX	23	22	25	18	22	30	65	65	38	20	24	29
MIN	21	18	16	17	17	19	22	18	16	14	14	13
AC-FT	1340	1200	1100	1060	1070	1360	2020	1690	1230	1010	1150	1010

	1989 OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL	559	568	477	416	447	950	892	699	544	568	683	616
MEAN	18.0	18.9	15.4	13.4	16.0	30.6	29.7	22.5	18.1	18.3	22.0	20.5
MAX	32	25	18	15	18	118	58	38	26	31	39	52
MIN	16	17	12	13	12	16	20	16	15	15	17	17
AC-FT	1110	1130	946	825	887	1880	1770	1390	1080	1130	1350	1220

	1990 OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL	588	597	660	635	519	588	696	888	632	718	799	512
MEAN	19.0	19.9	21.3	20.5	18.5	19.3	23.2	28.6	21.1	23.2	25.8	17.1
MAX	27	21	22	36	27	23	31	98	38	33	56	19
MIN	18	18	20	18	17	17	16	21	15	18	17	16
AC-FT	1170	1180	1310	1260	1030	1190	1380	1760	1250	1420	1580	1020

	1991 OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL	526	515	533	504	463	534	597	894	846	483	507	478
MEAN	17.0	17.2	17.2	16.3	16.5	17.2	19.9	28.8	28.3	15.6	16.4	15.9
MAX	20	19	19	17	18	20	24	59	48	21	36	25
MIN	16	16	16	16	16	16	17	17	21	14	14	13
AC-FT	1040	1020	1080	1000	918	1060	1180	1770	1660	958	1010	946

	1992 OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL	553	579	583	528	511	605	447	391.0	562	505	439	489
MEAN	17.8	19.3	18.8	17.0	17.6	19.5	14.9	12.6	18.7	16.3	14.2	16.3
MAX	20	24	22	18	21	21	18	20	52	35	23	21
MIN	16	17	18	16	16	18	12	8.0	13	12	11	13
AC-FT	1100	1150	1180	1050	1010	1200	887	776	1110	1000	671	970

STATISTICS OF MONTHLY MEAN DATA FOR WATER YEARS 1984 - 1994 BY WATER YEAR (WY)

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
MEAN	20.4	20.1	18.5	18.1	19.0	23.8	28.2	28.6	24.9	20.5	20.5
MAX	26.7	25.7	22.6	25.6	24.4	30.6	38.7	43.9	42.7	34.1	27.7
(WY)	1984	1984	1984	1984	1986	1989	1985	1984	1984	1987	1986
MIN	17.0	16.7	15.4	13.4	16.0	17.2	14.9	12.6	18.1	15.6	14.2
(WY)	1991	1986	1989	1989	1989	1991	1992	1992	1989	1991	1991

Table AII-1
Summary Flow Statistics for Blacktail Creek and Silver Bow Creek

	Blacktail Creek at Butte Water Years 1989-1993		Silver Bow Creek Below Blacktail Creek Water Years 1984-1993	
Flow Statistic	Flow (cfs)	Sample Date	Flow (cfs)	Sample Date
Annual mean	10.2		21.7	
Highest annual mean	11.1	1989	28.4	1984
Lowest annual mean	8.39	1992	16.9	1992
Highest daily mean	48	06/16/93	118	03/11/89
Lowest daily mean	4.4	09/03/92	8.0	05/08/92
Annual 7-day minimum	4.7	09/01/92	11	05/02/92
Instantaneous peak flow	171*	06/11/92	320**	05/29/90
Instantaneous peak stage	4.29	08/13/93	3.72	05/29/90
Instantaneous low flow	3.9	09/03/92	7.1	05/07/92
Annual runoff (acre-ft)	7,370		15,730	
10% exceeds	15		30	
50% exceeds	9.1		19	
90% exceeds	7		16	
<p>* Revised, from indirect measurement; gage height, 3.81 feet.</p> <p>** From indirect measurement.</p> <p>Source: USGS, 1994.</p>				



United States Department of the Interior

GEOLOGICAL SURVEY

Water Resources Division
Federal Building, Room 428
301 South Park Avenue, Drawer 10076
Helena, Montana 59626-0076

May 14, 1990

Mr. Ted Duaime
Montana Bureau of Mines
and Geology
Butte, Montana 59701

Dear Ted:

Attached are the preliminary results of the seepage run (streamflow gain-loss determination) made on Silver Bow Creek on April 12, 1990. Also included are copies of portions of USGS quad maps showing measuring site locations. Please give me a call (449-5263) if you have any questions.

Sincerely,

Charles Parrett
Supervisory Hydrologist

Attachments

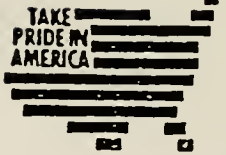
Blacktail-Silver Bow Creek Seepage Study, April 12, 1990

1.	Blacktail Creek nr. Butte	12-3232.00		3.69	
2.	Blacktail Cr at Ninemile Junction			4.00	
3.	Little Blacktail Creek		RB	.68	
4.	Blacktail Creek S.E. of Airport			3.99	
4A.	Irrigation ditch bypass		RB	.05	
5.	Blacktail Creek above Butte Country Club			4.58	
6.	Reese Creek		RB	0.00	
7.	Basin Creek				.67 LF
8.	Blacktail Creek at Harrison Ave.			8.49	
9.	Sand Creek				.01 LF
10.	Grove Gulch				.67 LF
11.	Blacktail Creek at Butte	12-3232.40		12.9	
					⋮
12.	Silver Bow Creek above mouth of Blacktail Cr.			.30	
	..... Blacktail Creek enters on Left Bank				<-----V
12A.	Drainage blw Blacktail Creek mouth		RB	.05	
13.	Missoula Creek		RB	.18	
14.	Silver Bow Creek ab Sewage Treatment Plant			14.1	
15.	Butte Sewage Treatment Plant discharge		RB	7.1	
16.	Silver Bow Creek blw Sewage Treatment Plant			21.8	
17.	Silver Bow Creek blw Blacktail Cr	12-3232.50		21.0	
18.	Unnamed Trib blw gage		RB	0.0	
19.	Unnamed Trib blw gage			0.0	LF
20.	Whiskey Gulch nr. Rocker		RB	.05	
21.	Silver Bow Creek at Rocker			21.0	



United States Department of the Interior

GEOLOGICAL SURVEY
Water Resources Division
Federal Building, Room 428
301 South Park Avenue, Drawer 10076
Helena, Montana 59626-0076



November 30, 1990

Mr. Ted Duaine
Montana Bureau of Mines
and Geology
Butte, Montana 59701

Dear Ted:

Attached are the preliminary results of the seepage run (streamflow gain-loss determination) made on Silver Bow Creek On November 8, 1990. Also included are copies of portions of USGS quad maps showing measuring site locations. Please give me a call (449-5263) if you have any questions.

Sincerely, '

Charles Parrett
Supervisory Hydrologist

Enclosures

Site No.	Stream name (station number)	Discharge, cfs
1.	Blacktail Creek nr. Butte (12-323200)	0.84
2.	Blacktail Cr at Ninemile Junction	1.07
3.	Little Blacktail Creek	0.11
4.	Blacktail Creek S.E. of Airport	EST 0.25
4A.	Irrigation ditch bypass	0.00
5.	Blacktail Creek above Butte Country Club	1.31
6.	Reese Creek	0.00
7.	Basin Creek	0.67
7A.	STORM DRAIN	EST 0.75
8.	Blacktail Creek at Harrison Ave.	4.73
9.	Sand Creek	0.06
10.	Grove Gulch	0.00
10A.	POND DISCHARGE	0.60
11.	Blacktail Creek at Butte (12-3232.40)	9.1
12.	Silver Bow Creek above mouth of Blacktail Cr	EST 0.3
12A.	Drainage blw Blacktail Creek mouth	EST 0.2
13.	Missoula Creek	1.30
14.	Silver Bow Creek ab Sewage Treatment Plant	11.8
15.	Butte Sewage Treatment Plant discharge	6.9
16.	Silver Bow Creek blw Sewage Treatment Plant	19.6
17.	Silver Bow Creek blw Blacktail Cr (12-3232.50)	20.3
18.	Unnamed Trib blw gage	0.00
19.	Unnamed Trib blw gage	0.00
20.	Whiskey Gulch nr. Rocker	EST 0.05
21.	Silver Bow Creek at Rocker	17.6 *

* Apparent decrease in flow from site 17 is the result of a flow change over time, evidently at the sewage treatment plant, and not a loss to groundwater.

APPENDIX I

BERKELEY PIT WATER QUALITY DATA

Appendix I. Berkeley Pit Water Quality Data.

I-1

Analy. Lab	Physical Parameters											
	Date (mm/dd/yy)	Time (Hours)	Sample Depth (Feet)	SC (UMIHOS)	pH	Field Eh (MV)	DO (MG/L)	Temp. (C)	Lab SC (UMIHOS)	pH	Hardness (MG/L)	Alkalinity (MG/L)
MBMG	11/21/84	10:55	Surface	4320	2.64	NA	NA	5.6	4250	2.92	1975.8	0.0
MBMG	11/21/84	10:55	50-75	4200	2.78	NA	NA	6.5	4865	4.68	2087.5	3.0
MBMG	6/18/85	10:10	Surface	NA	2.26	NA	NA	10.2	3965	2.75	1637.9	0.0
MBMG	6/18/85	10:10	~ 100	NA	2.48	NA	NA	10.4	5585	2.65	2160.5	0.0
MBMG	10/17/86		0	NA	NA	NA	NA	NA	NA	NA	1674.5	0.0
MBMG	10/17/86		110	NA	NA	NA	NA	NA	NA	NA	2170.0	0.0
MBMG	10/17/86		220	NA	NA	NA	NA	NA	NA	NA	2321.4	0.0
MBMG	10/17/86		330	NA	NA	NA	NA	NA	NA	NA	2417.1	0.0
MBMG	10/17/86		390	NA	NA	NA	NA	NA	NA	NA	2414.6	0.0
MBMG	10/14/87		0	4260	2.76	817	6.89	11.5	NA	2.24	1707.4	0.0
MBMG	10/14/87		3	4240	2.72	720	5.47	8.2	NA	2.20	1807.3	0.0
MBMG	10/14/87		10	5200	2.84	643	0.07	11.5	NA	2.10	2032.8	0.0
MBMG	10/14/87		50	6180	2.95	570	0.10	12.1	NA	2.10	2230.9	0.0
MBMG	10/14/87		100	6980	3.08	501	0.13	13.3	NA	2.04	2394.0	0.0
MBMG	10/14/87		200	7050	3.15	457	0.13	13.5	NA	2.42	2400.4	0.0
MBMG	10/14/87		300	7080	3.15	468	0.13	13.5	NA	2.44	2397.9	0.0
MBMG	10/14/87		400	7100	3.14	463	0.13	13.7	NA	2.24	2383.8	0.0
MBMG	05/21/91	1600	3.4	7030	2.47	610	5.34	13.0	6871	2.70	2840.3	0.0
MBMG	05/21/91	1315	400	8050	2.69	416	0.06	6.1	7240	2.73	2947.3	0.0
ARCO	05/21/91	1600	3.4	8977	2.48	613	NA	13.1	NA	NA	2750.0	4.8
ARCO	05/21/91	1315	400	12066	2.67	417	NA	6.1	NA	NA	2720.0	4.8
ARCO	05/21/91	1600	3.4DUP	8977	2.48	613	NA	13.1	NA	NA	2650.0	4.8
ARCO	05/21/91	1315	400DUP	12066	2.67	417	NA	6.1	NA	NA	2650.0	4.8
CDM - FPC	05/21/91		400	8320	2.67	417	0.60	6.1	NA	NA	3000.0	0.0
MBMG	05/22/91	1600	3	6090	2.73	548	NA	15.2		2.73	2918.0	0.0
MBMG	05/22/91	1428	225	6490	2.84	410	NA	13.5	10405	2.75	2949.0	0.0

Analy. Lab	Date (mm/dd/yyyy)	Dissolved Concentration														Al (ug/l)	Ag (ug/l)
		Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Fe (mg/l)	Mn (mg/l)	SiO2 (mg/l)	HCO3 (mg/l)	CO3 (mg/l)	Cl (mg/l)	SO4 (mg/l)	NO3-N (mg/l)	F (mg/l)			
MBMG	11/21/84	455.0	204.0	63.2	4.9	214.0	87.5	83.6	0.0	0.0	12.0	3707	0.2	4.2	120000	17	
MBMG	11/21/84	447.0	236.0	61.7	4.4	256.0	106.0	87.6	3.7	0.0	12.3	4410	0.1	5.8	142000	30	
MBMG	6/18/85	412.0	148.0	64.8	7.9	114.0	68.1	85.6	0.0	0.0	12.3	3200	0.2	3.7	86000	33	
MBMG	6/18/85	435.0	261.0	60.3	8.8	451.0	116.0	100.0	0.0	0.0	8.3	5550	0.2	13.6	172000	43	
MBMG	10/17/86	425.0	149.0	59.3	12.9	177.0	64.0	78.9	NA	NA	NA	NA	NA	NA	91600	19	
MBMG	10/17/86	457.0	250.0	64.7	19.5	685.0	122.0	104.0	NA	NA	NA	NA	NA	NA	171000	32	
MBMG	10/17/86	450.0	291.0	65.8	24.3	918.0	144.0	108.0	NA	NA	NA	NA	NA	NA	192000	37	
MBMG	10/17/86	457.0	310.0	66.5	26.2	1010.0	154.0	109.0	NA	NA	NA	NA	NA	NA	201000	43	
MBMG	10/17/86	456.0	310.0	65.4	26.2	1020.0	156.0	111.0	NA	NA	NA	NA	NA	NA	203000	43	
MBMG	10/14/87	425.0	157.0	70.0	17.2	183.0	65.6	65.5	0.0	0.0	11.0	3580	1.5	6.0	97900	22	
MBMG	10/14/87	444.0	169.0	69.6	17.7	231.0	70.8	69.2	0.0	0.0	11.0	3760	1.1	6.0	106000	14	
MBMG	10/14/87	463.0	213.0	67.5	18.0	376.0	86.7	77.8	0.0	0.0	11.0	4720	0.5	6.0	144000	68	
MBMG	10/14/87	483.0	249.0	67.1	22.0	711.0	115.0	95.5	0.0	0.0	11.5	5810	0.1	7.6	162000	77	
MBMG	10/14/87	484.0	288.0	68.6	28.5	982.0	142.0	98.6	0.0	0.0	12.5	6710	0.4	8.4	187000	66	
MBMG	10/14/87	480.0	292.0	68.6	29.5	983.0	143.0	109.0	0.0	0.0	12.0	6600	0.2	8.4	186000	79	
MBMG	10/14/87	479.0	292.0	69.4	29.2	984.0	143.0	111.0	0.0	0.0	12.5	6500	0.2	8.4	189000	68	
MBMG	10/14/87	475.0	291.0	68.8	29.7	1010.0	147.0	112.0	0.0	0.0	12.0	6780	0.2	8.4	191000	67	
MBMG	05/21/91	460.0	411.0	66.1	15.4	666.0	191.0	94.4	0.0	0.0	10.8	7261	0.2	14.3	268700	<6	
MBMG	05/21/91	488.0	420.0	69.7	20.9	1095.0	182.0	98.5	0.0	0.0	11.1	8084	0.5	18.0	284900	<6	
ARCO	05/21/91	431.0	407.0	72.1	18.2	593.0	155.0	39.7*	NA	NA	21.4	15300	0.1	26.2	268000	70	
ARCO	05/21/91	442.0	162.0	71.3	23.8	970.0	162.0	42.4*	NA	NA	27.3	17200	0.1	32.0	271000	3.3	
ARCO	05/21/91	415.0	392.0	67.9	17.5	567.0	163.0	40.1*	NA	NA	22.6	17400	0.1	29.5	257000	2.8	
ARCO	05/21/91	428.0	384.0	69.9	22.8	943.0	158.0	41.9*	NA	NA	26.4	17800	0.1	31.6	265000	4.6	
CDM-FPC	05/21/91	506.0	426.0	57.4	23.6	1030.0	186.0	50.6*	0.0	0.0	NA	13000	0.0	NA	298000	5	
MBMG	05/22/91	473.0	422.0	71.2	15.7	649.0	190.0	100.0	0.0	0.0	15.1	7217	0.2	32.9	274200	<6	
MBMG	05/22/91	492.0	418.0	68.3	20.3	1088.0	182.0	97.0	0.0	0.0	10.9	8010	0.2	19.2	288000	<6	

Analy. Lab	Date (mm/dd/yr)	Dissolved Concentration															Zr (ug/l)
		As (ug/l)	B (ug/l)	Cd (ug/l)	Co (ug/l)	Cr (ug/l)	Cu (ug/l)	Li (ug/l)	Mo (ug/l)	Ni (ug/l)	Pb (ug/l)	Sr (ug/l)	Ti (ug/l)	V (ug/l)	Zn (ug/l)		
MBMG	11/21/84	54	110	1230	850	61	89600	100	170	630	170.0	860	79	28	196000	19.0	
MBMG	11/21/84	197	200	1540	980	97	164000	120	310	850	160.0	880	94	66	255000	35.0	
MBMG	6/18/85	21	100	1000	64	48	63000	110	70	470	NA	970	76	31	134000	31.0	
MBMG	6/18/85	426	150	1620	1170	92	229000	150	200	830	NA	900	82	168	329000	47.0	
MBMG	10/17/86	16	150	1000	570	4	114000	160	140	460	NA	860	10	29	178000	<4	
MBMG	10/17/86	33	250	1620	940	42	196000	230	210	790	NA	1030	15	220	375000	23.0	
MBMG	10/17/86	41	330	1740	1050	50	204000	250	230	910	NA	1020	22	270	460000	49.0	
MBMG	10/17/86	50	390	1800	1060	55	214000	270	280	970	NA	1020	14	310	472000	50.0	
MBMG	10/17/86	123	400	1690	1070	47	213000	260	250	950	NA	1000	27	310	477000	62.0	
MBMG	10/14/87	4.2	130	1090	630	2	127000	120	20	440	220	1070	20	23	198000	47.0	
MBMG	10/14/87	3.9	210	1450	630	33	134000	140	80	560	610	1090	48	80	214000	150.0	
MBMG	10/14/87	4.2	150	1710	690	35	149000	160	90	700	720	1120	60	110	269000	180.0	
MBMG	10/14/87	0.8	200	1890	930	<2	205000	200	100	860	980	1060	62	290	390000	230.0	
MBMG	10/14/87	335	220	1740	1370	<2	205000	230	150	980	1340	1120	56	340	391000	240.0	
MBMG	10/14/87	755	170	1760	1190	<2	199000	230	130	990	1390	1120	58	340	469000	260.0	
MBMG	10/14/87	695	200	1780	1020	<2	199000	230	110	980	1360	1130	58	330	470000	250.0	
MBMG	10/14/87	1010	190	1780	1110	<2	196000	220	120	990	1240	1120	62	330	478000	250.0	
MBMG	05/21/91	209	380	1708	1690	56	178800	251	50	1030	80	1330	80	41	506300	<6	
MBMG	05/21/91	880	420	1573	1830	54	186600	269	70	1060	<50	1350	80	178	546600	<6	
ARCO	05/21/91	190	NA	1870	NA	50	150000	NA	NA	893	51.8	NA	NA	NA	441000	NA	
ARCO	05/21/91	830	NA	1770	NA	63	171000	NA	NA	860	96.4	NA	NA	NA	484000	NA	
ARCO	05/21/91	215	NA	1790	NA	49	158000	NA	NA	832	46.8	NA	NA	NA	439000	NA	
ARCO	05/21/91	892	NA	1730	NA	60	166000	NA	NA	826	40.2	NA	NA	NA	471000	NA	
CDM-FPC	05/21/91	449	NA	2030	NA	5	195000	NA	NA	1060	35	NA	NA	NA	558000	NA	
MBMG	05/22/91	209	410	1807	1680	54	177800	262	60	1110	<50	1420	76	19	505400	<6	
MBMG	05/22/91	830	400	1572	1800	55	191300	266	50	1050	80	1340	75	180	552400	<6	

Appendix I. Berkeley Pit Water Quality Data.

Analy. Lab	Date (mm/dd/yy)	Time (Hours)	Sample Depth (Feet)	Physical Parameters								
				SC (UMHOS)	pH	Field Eh (MV)	DO (MG/L)	Temp. (C)	Lab SC (UMHOS)	pH	Hardness (MG/L)	Alkalinity (MG/L)
ENERGY	05/22/91	1600	3	NA	2.73	NA	NA	15.2	7360	2.40	2930.0	0.0
ENERGY	05/22/91	1428	225	NA	2.84	NA	NA	13.5	7940	2.60	3050.0	0.0
BEUERMAN	05/22/91	1600	3	NA	2.73	NA	NA	15.2	NA	NA	NA	NA
MBMG**	2/28/92	NA	0-0.3	850	2.95	NA	NA	NA	955	3.36	209.7	0.0
MBMG**	2/28/92	NA	0.3-0.6	1480	2.74	NA	NA	NA	1600	3.00	385.1	0.0
MBMG**	2/28/92	NA	0.6-0.9	1830	2.59	NA	NA	NA	1975	2.95	510.3	0.0
MBMG**	2/28/92	NA	0.9-1.2	2150	2.48	NA	NA	NA	2240	2.94	603.4	0.0
MBMG	3/3/92	1100	~ 3	4160	2.87		NA	3.7	4480	2.80	1551.0	0.0
ARCO	8/18-19/92	NA	3	8531	2.65	551	NA	17.9	NA	NA	2925.0	<10
ARCO	8/18-19/92	NA	200	7390	2.78	408	NA	10.8	NA	NA	2767.0	<10
ARCO	8/18-19/92	NA	3DUP	8531	2.70	551	NA	17.9	NA	NA	2993.0	<10
ARCO	8/18-19/92	NA	200DUP	7390	2.81	408	NA	10.8	NA	NA	2744.0	<10
MBMG	8/19/92	NA	3	NA	NA	NA	NA	NA	5960	2.78	3016.5	NA
MBMG	8/19/92	NA	200	NA	NA	NA	NA	NA	6270	2.92	2755.1	NA
MBMG	5/18/93	13:05	3	5340	2.91	222	NA	19.6	5390	2.90	2761.3	0.0
MBMG	10/7/93	14:30	200	8785	2.55	401	NA	11.9	6580	2.87	5795.1	0.0
MBMG	10/21/93	13:00	200	7750	2.57	NA	NA	10.0	7860	2.89	2749.4	0.0
MBMG	12/1/93	12:10	200	9680	2.64		NA	9.6	7940	2.89	2526.0	0.0
MBMG	12/9/93	10:05	200	8690	2.54		NA	8.6	8000	2.96	2725.1	0.0
MBMG	4/19/94	15:00	150	8770	2.44	446	NA	9.0	8040	2.40	2920.1	0.0
MBMG	4/19/94	09:00	200	8770	2.45	445	NA	9.0	8030	2.38	2948.1	0.0

Analy. Lab	Date (mm/dd/yy)	Dissolved Concentration														Ag (ug/l)
		Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Fe (mg/l)	Mn (mg/l)	SiO ₂ (mg/l)	HCO ₃ (mg/l)	CO ₃ (mg/l)	Cl (mg/l)	SO ₄ (mg/l)	NO ₃ -N (mg/l)	F (mg/l)	Al (ug/l)	
ENERGY	05/22/91	493.0	413.0	NA	NA	483.0	NA	132.0	NA	NA	NA	NA	NA	NA	NA	17
ENERGY	05/22/91	538.0	415.0	NA	NA	941.0	NA	141.0	NA	NA	NA	NA	NA	NA	NA	11
BEUERMAN	05/22/91	596.5	403.1	35.1	9.9	1033.0	196.0	55.6*	NA	NA	NA	NA	NA	NA	284300	140
MBMG**	2/28/92	48.2	21.7	3.5	0.4	11.4	10.9	2.4	0.0	0.0	5.7	400	<.1	1.4	15120	<10
MBMG**	2/28/92	69.5	51.4	7.2	0.9	36.0	25.0	6.9	0.0	0.0	10.5	823	<.1	2.6	33900	<10
MBMG**	2/28/92	90.3	69.2	9.1	1.9	50.5	34.5	10.4	0.0	0.0	11.5	1121	<.1	3.3	45300	<10
MBMG**	2/28/92	96.1	88.3	13.4	1.8	46.6	43.7	11.6	0.0	0.0	11.5	1300	0.7	4.0	56500	<10
MBMG	3/3/92	242.0	230.0	33.0	5.6	234.0	113.7	56.1	0.0	0.0	42.1	3823	0.6	6.9	146000	<1
ARCO	8/18-1992	499.0	408.0	53.5	8.5	411.0	239.0	50.4*	<10	0.0	15.0	5620	<.1	<0.5	240000	<3
ARCO	8/18-1992	486.0	377.0	56.8	15.6	1077.0	208.0	51.0*	<10	0.0	16.0	6530	<.1	<0.5	246000	<3
ARCO	8/18-1992	505.0	421.0	56.2	9.0	415.0	242.0	51.8*	<10	0.0	15.0	5760	<.1	<0.5	248000	<3
ARCO	8/18-1992	484.0	373.0	55.4	15.3	1075.0	207.0	50.5*	<10	0.0	16.0	6500	<.1	<0.5	243000	<3
MBMG	8/19/92	463.0	452.0	71.0	10.5	373.0	233.0	103.0	0.0	0.0	30.0	6930	0.2	21.5	79900	<10
MBMG	8/19/92	444.0	400.0	72.3	18.8	966.0	191.0	101.0	0.0	0.0	77.2	8014	<.2	45.2	80500	<10
MBMG	5/18/93	430.0	410.0	68.0	11.0	293.0	194.0	87.0	0.0	0.0	49.0	6080	<.4	29.1	252000	<10
MBMG	10/7/93	432.0	417.0	76.0	16.9	1083.0	191.0	103.0	0.0	0.0	34.3	7508	<.2	46.8	288000	<4
MBMG	10/21/93	417.0	415.0	75.9	17.5	1088.0	196.0	103.0	0.0	0.0	15.0	7622	<.25	41.0	288000	<4
MBMG	12/1/93	405.0	368.0	64.8	15.2	1035.0	180.0	94.7	0.0	0.0	15.5	7994	<.5	38.7	265000	<4
MBMG	12/9/93	432.0	400.0	71.0	17.2	1141.0	187.0	91.6	0.0	0.0	16.9	7882	0.3	37.4	275000	<4
MBMG	4/19/94	459.0	431.0	78.5	18.5	1160.0	198.0	106.0	0.0	0.0	14.2	7650	<.25	41.6	293000	<4
MBMG	4/19/94	457.0	439.0	76.7	18.0	1107.0	206.0	104.0	0.0	0.0	16.5	7643	<.25	41.8	292000	<4

Analy. Lab	Date (mm/dd/yy)	Dissolved Concentration															
		As (ug/l)	B (ug/l)	Cd (ug/l)	Co (ug/l)	Cr (ug/l)	Cu (ug/l)	Li (ug/l)	Mo (ug/l)	Ni (ug/l)	Pb (ug/l)	Sr (ug/l)	Ti (ug/l)	V (ug/l)	Zn (ug/l)	Zr (ug/l)	
ENERGY	05/22/91	70	NA	2160	NA	NA	180000	NA	<5	NA	130	NA	NA	NA	NA	504000	NA
ENERGY	05/22/91	46	NA	2190	NA	NA	193000	NA	30	NA	150	NA	NA	NA	NA	578000	NA
BEUERMAN	05/22/91	240	NA	2850	2000	10	186400	NA	400	2900	200	1670	NA	300	596000	NA	NA
MBMG**	2/28/92	0.5	<100	120	NA	<10	10500	10	<40	7	<50	139	<8	<10	28800	<8	<8
MBMG**	2/28/92	2.3	<100	278	NA	10	21200	23	<40	134	<50	203	10	<10	57500	<8	<8
MBMG**	2/28/92	3.9	110	386	NA	<10	26900	49	<40	220	190.0	248	20	<10	82200	49.0	49.0
MBMG**	2/28/92	2	120	503	NA	<10	31800	50	<40	244	140.0	272	20	<10	97100	20.0	20.0
MBMG	3/3/92	120	180	1240	387	2	93000	144	<50	685	40.9	682	79	<1	261000	<10	<10
ARCO	8/18-19/92	150	NA	2550	NA	80	173000	NA	NA	1080	9.0	NA	NA	NA	537000	NA	NA
ARCO	8/18-19/92	1350	NA	2280	NA	105	177000	NA	NA	990	7.0	NA	NA	NA	579000	NA	NA
ARCO	8/18-19/92	150	NA	2560	NA	94	178000	NA	NA	1110	7.0	NA	NA	NA	542000	NA	NA
ARCO	8/18-19/92	1350	NA	2280	NA	105	175000	NA	NA	1010	6.0	NA	NA	NA	578000	NA	NA
MBMG	8/19/92	103	<100	2300	1440	41	189000	272	<40	1250	48.0	1700	<50	<20	519000	<100	<100
MBMG	8/19/92	1303	<100	1960	1360	60	190000	296	<40	1280	97.0	1460	<20	123	540000	<200	<200
MBMG	5/18/93	108	<100	2032	1235	80	162000	266	95	908	43.0	1519	<10	<10	437000	<50	<50
MBMG	10/7/93	1190	<50	1927	1367	100	201000	350	53	1090	89.6	1380	28	120	587000	<50	<50
MBMG	10/21/93	1200	<60	1900	1337	60	195000	333	70	1135	82.7	1320	28	117	595000	<50	<50
MBMG	12/1/93	1210	<80	1773	1363	63	180000	282	48	921	80.1	1150	<10	122	585000	<40	<40
MBMG	12/9/93	1220	<80	1840	1361	66	176000	281	23	911	81.6	1144	<10	122	589000	<40	<40
MBMG	4/19/94	1300	<80	1928	1321	60	195000	358	58	1175	82.0	1441	<10	112	606000	235.0	235.0
MBMG	4/19/94	1210	<80	1895	1302	61	198000	356	72	1165	134.0	1422	<10	103	608000	226.0	226.0

Source: Duane, T.E. 1992 and 1994. Personal Communication to Ann Maest of RCG/Hagler Bailly containing unpublished MBMG data.

Notes: NA - data not available

1991-92 data preliminary, subject to data validation

* - value reported as silicon

MBMG** Samples are of pit ice

APPENDIX II

BEDROCK GROUNDWATER QUALITY DATA

- A - Butte Mine Flooding**
- B - Bedrock Monitoring Wells**
- C - NRDA Bedrock Monitoring Results**
- D - Bedrock Aquifer Baseline Water Quality Data**

Physical Parameters								Dissolved Concentration													
Site	Date (mm/dd/yy)	Time (Hours)	SWL (FT)	FIELD		Temp (C)	Alkalinity (MG/L)	Fe (mg/l)	Mn (mg/l)	Cl (mg/l)	SO4 (mg/l)	NO3 (mg/l)	Al (ug/l)	Cd (ug/l)	Cr (ug/l)	Cu (ug/l)	Pb (ug/l)	Zn (ug/l)	As (ug/l)	Se (ug/l)	
				Sample pH	Depth																
Anselmo (East Camp System)	07/31/86	13:40	989.9	6.6		12.0	169.0	0.0	9.66	30.5	882	1.31	<30	8	<2	26		20000		9.2	
	09/26/86	13:30	970.9	6.1	1990	12.2	226.9	0.1	28.40	27.1	1095	0.11	<30	63	<2	44		53000		29.0	
	05/31/88	13:35	843.1	6.3	965	21.0	141.8	0.4	9.28	21.1	617	0.17	<30	45	<2	1600		24900		8.6	
	11/30/88	15:10	817.3	6.1	2353	14.5	287.9	0.3	11.00	29.3	866	0.06	<30	<2	<2	12	<40	14600		8.4	
	02/27/89	14:45	808.2	6.5		14.2	250.2	0.6	10.20	29.1	939	<.02	<30	<2	<2	8	12	11000		14.0	
	03/30/89	14:38	804.5	6.6	1952	14.0	205.3	0.1	19.30	27.0	972	0.20	50	38	6	28	69	26000		10.0	
	04/26/89	14:57		6.5	2304	13.0	193.7	0.3	35.30	32.0	1200	0.20	<30	69	<2	40	<40	57500		11.0	
	08/04/89	19:00	798.0	6.4	2045	15.0	262.5	4.0	22.10	30.2	1060	0.19	<30	5	6	23	<40	17870		94.0	
	12/28/89	15:00	785.5	6.3	2100	14.0	255.9	0.2	16.56	31.2	1000	<.06	82	<5	15	24	50	9620		9.6	
	05/01/90	15:50	776.1	6.1	2020	15.0	256.7	0.1	16.57	29.4	957	0.06	<40	11	<5	<4	60	11300		6.9	
	05/91			6.7	1770	15.0	274.0	0.2	10.20		823	<.5R	96	14.1	<7.7	24	1.1	5570		19.4	
	08/91			6.7	1777	15.5	262.0	0.1	11.10		796	<.5R	119	6.9	<5.2	35.7	4.8	8850		4.2	
Belmont	04/28/83	11:45	1,867.2	5.0	2121	11.0	2.4	1.6	12.20	31.2	1200	4.80	3200	230	9	2700	<40	36800		2.3	
	10/13/83	12:30		3.7			0.0	4.4	11.50				6600	210	11	3945	<40	3320		5.0	
	04/26/84	12:10	1,165.6	3.4	7300	1.0	0.0	1620.0	129.00				29900	940	140	36400		446000		8420.0	
	07/26/84	11:02	1,101.2	5.7	1730	14.5	43.2	4.1	9.92	24.1	1040	0.85	600	170	6	1360		30800		57.0	
	10/18/84	12:20	1,050.7	3.4	4470	13.0	0.0	748.0	57.60	31.0	4100	11.10	118000	650	56	6430		264000		5100.0	
	02/22/86	12:49	878.0	5.1	1770	11.0	22.1	0.3	8.95	26.9	1020	0.08	400	96	4	530		21200		43.0	
	05/29/86	13:30	856.9	5.8	1630	14.6	26.0	1.1	8.46	25.5	907	0.06	40	110	<2	260		23700		5.2	
	06/26/86	09:50	852.2	5.6	1230	12.8	62.4	2.0	8.42	24.5	886	0.06	260	140	<2	860		22800		8.5	
	07/31/86	09:00	839.5	5.6	1695	12.6	48.4	2.1	9.00	23.2	948	0.20	540	100	<2	900		23000		12.0	
	09/26/86	10:30	825.8	5.9	1260	9.9	54.7	1.8	7.90	22.8	826	0.08	130	110	<2	400		20900		8.4	
	05/31/88	09:51	698.8	6.0	662	11.0	94.1	1.2	7.35	22.4	792	0.14	80	110	<2	550		23600		8.0	
	07/28/88	09:20	685.7	5.9	1340	12.4	72.0	2.2	7.66	23.7	794	0.24	90	100	<2	480	<40	21400		13.0	
Chester	11/30/88	10:50	670.1	5.9	1508	9.5	58.6	0.6	7.08	22.9	765	0.13	80	76	<2	65	<40	17300		8.2	
	02/27/89	09:53	659.4	5.9		12.0	30.4	0.7	7.65	22.7	906	0.03	420	75	7	590	19	20900		17.0	
	03/30/89	10:00	654.4	6.0	1649	12.0	31.3	0.6	7.94	22.7	894	1.23	400	79	6	520	22	20100		13.0	
	04/26/89	10:15	653.6	5.8	1661	12.0	25.2	0.4	8.19	23.5	909	1.47	420	70	2	530	<40	21100		16.0	
	08/04/89	09:50	649.5	5.4	1720	13.0	39.0	0.8	8.48	23.1	955	0.04	533	75	<2	611	<40	21610		12.0	
	05/91			6.2	1689	13.5	32.0	0.4	8.12		888	0.7R	314	189	<7.7	186	2.4	2480		7.5	
	08/91			5.7	1600	14.0	44.0	0.9	9.16		818	<.5R	635	224	<5.2	916	8.5	2790		14.9	
	05/91			6.1	1029	13.3	85.0	0.4	16.50		444	<.5R	968	95.4	<7.7	10900	1.7	23700		21.7	

Physical Parameters										Dissolved Concentration										
Site	Date (mm/dd/yy)	Time	SWL (F/T)	Sample Depth	FIELD			Fe (mg/l)	Mn (mg/l)	Cl (mg/l)	SO4 (mg/l)	NO3 (mg/l)	Al (ug/l)	Cd (ug/l)	Cr (ug/l)	Cu (ug/l)	Pb (ug/l)	Zn (ug/l)	As (ug/l)	Se (ug/l)
					SC (UMHOS)	pH	Temp (C)														Alkalinity (MG/L)
Chester	08/91				5.8	1352	16.0	39.0	0.4	31.40		725 <0.5R	3010	174	<5.2	20800	3	42200	16.7	
Granite Mountain	06/25/87	12:50	1,206.0		6.1	1590		92.0	0.3	27.00	9.9	1932	2.28	230	20	<2	420	24300	4.5	
	05/31/88	10:35	1,169.7		6.1	2020	15.0	82.4	0.1	32.00	9.3	1960	0.05	120	19	5	180	14200	4.4	
	03/03/89	10:45	1,108.8		7.0		15.0	76.4	2.3	50.30	10.0	2050	0.14	210	7	<2	35	<4	11900	14.0
	08/04/89	12:35	1,099.1		5.8	3250	10.9	90.1	7.0	68.70	19.6	2220	0.43	327	7	2	138	<40	14980	10.0
	05/01/90	12:45	1,074.0		5.7	3520	11.0	0.0	114.0	100.00	10.7	2660	<0.06	320	<5	<5	97	110	16800	19.0
	5/91				5.8	2893	22.5	34E	137E	94E		2560E		574E	35.7E	<7.7E	251S	1.9E	14400E	27E
	8/91				5.72	3770	19	46E	144E	97.3S		247E		982E	<2.9E	<5.2E	1280E	6.3E	17100E	32.6E
Kelley	07/28/83	09:07	1,905.6		2.3	9070	18.0	0.0	965.0	238.00	13.4	9600	0.45	509000	4160	340	3410	<40	708000	2040.0
	10/13/83	09:40	1,691.8		4.3	3900	18.0	37.4	72.7	34.60	58.2	3310	1.34	41500	460	43	23800	<40	90300	372.0
	02/16/84	09:43	1,494.2		4.4	5400	17.1	0.0	286.0	93.40	36.8	4110	0.19	73600	1040	102	34000	160	22700	102.0
	04/26/84		1,437.3		3.7	6800		0.0	1080.0	94.20				188000	660	106	43800		344000	2880.0
	07/12/84	14:08	1,388.2		4.2	4800	19.0	0.0	90.7	27.80				29500	170	15	2130	8540	136.0	
	07/12/84	14:30	1,388.2	2137	3.7	12100	20.0	0.0	3080.0	250.00	33.0	12800	3.39	448000	1970	200	800		853000	
	07/12/84	15:00	1,388.2	1788	3.6	12700	20.0	0.0	3270.0	244.00				464000	970	190	3040	824000	2780.0	
	07/12/84	15:20	1,388.2	1475	3.9	9900	21.0	0.0	2520.0	169.00	17.8	10400	0.13	325000	1220	120	7790	623000	5340.0	
	07/26/84	09:16	1,373.3		4.0	5725	20.1	0.0	867.0	75.10	36.7	5340	3.51	119000	470	90	2120	269000	1670.0	
	10/18/84	10:15	1,327.7		5.7	3500	14.0	7.2	0.4	13.90	44.3	2490	5.74	1430	130	101	280	32100	1.9	0.9
	11/30/84	09:20	1,304.8		3.6	7535	20.5	0.0	1633.0	129.00	31.3	8000	0.02	124000	950	140	90000	687000	5130.0	
	11/30/84	09:40	1,304.8	2200	3.6	7940	19.4	0.0	1629.0	129.00	31.3	7830	0.24	122000	1250	130	93400	666000	4730.0	
	11/30/84	09:55	1,304.8	1475	3.6	7710	19.9	0.0	1609.0	126.00	31.6	8080	0.24	122000	9990	120	91900	660000	4280.0	
	11/30/84	10:05	1,304.8	1788	3.7	7150	17.6	0.0	1590.0	125.00	32.0	7770	0.37	120000	1230	140	90700	652000	4640.0	
	05/30/85	10:25	1,233.4	1233	4.3	6010	17.0	0.0	871.0	87.20	29.0	5410	2.30	53900	490	51	10600	457000	1210.0	
	05/30/85	10:45	1,233.4	2200	3.5	16245	29.2	0.0	6030.0	439.00	17.5	23500	0.68	799000	1170	320	6480	1550000	16130.0	
	05/30/85	10:50	1,233.4	1788	3.5	16300	30.2	0.0	6200.0	456.00	16.6	24300	4.07	841000	1280	330	6200	1590000	16580.0	
05/30/85	11:00	1,233.4	1475	4.8	6360	18.4	0.0	1240.0	112.00	30.5	6440	0.12	63900	830	66	10900	596000	1870.0		
10/31/85	09:35	1,186.0	1186	5.9	3915	15.0	47.7	1.3	23.20	41.1	2492	0.29	330	36	<2	79	63500	1.5		
10/31/85	09:50	1,186.0	2200	4.6	6400	19.0	0.0	1320.0	118.00	29.1	6430	0.03	46000	160	85	340	498000	2880.0		
10/31/85	10:25	1,186.0	1788	4.8	5800	18.0	0.0	992.0	96.20	25.7	5490	1.65	23200	140	69	350	448000	241.0		
10/31/85	10:45	1,186.0	1475	4.8	5760	18.4	0.0	977.0	95.80	25.4	5430	0.30	23200	130	54	350	441000	4.6		
05/29/86	09:40	1,132.8	1132	4.8	4590	18.6	0.0	327.0	57.60	32.4	3480	0.05	9600	97	<2	3310	168000	11.8	0.2	

Physical Parameters										Dissolved Concentration													
Site	Date (mm/dd/yy)	Time	SWL (Ft)	Sample Depth	FIELD			SC (UMHOS)	Temp (C)	Alkalinity (MG/L)	Fe (mg/l)	Mn (mg/l)	Cl (mg/l)	SO4 (mg/l)	NO3 (mg/l)	Al (ug/l)	Cd (ug/l)	Cr (ug/l)	Cu (ug/l)	Pb (ug/l)	Zn (ug/l)	As (ug/l)	Se (ug/l)
					pH	SC	Depth																
Kelley	05/29/86	10:50	1,132.8	2200	5.6	4540	18.0	0.0			314.0	56.00	32.0	3400	0.08	8980	120	<2	3180		162000	83.2	0.2
	05/29/86	11:20	1,132.8	1132	5.0	9070	22.2	0.0			1840.0	158.00	21.4	8150	0.36	120000	78	<2	1760		567000	6800.0	0.4
	06/26/86				5.0	3110	20.9	0.0			363.0	59.80	34.3	3720	0.04	12500	110	<2	3760		177000	19.0	0.2
	07/31/86	14:45	1,118.3		5.2	3960	18.4	0.0			356.0	61.20	34.4	3433	3.00	6500	42	<2	4300		172000	12.0	0.3
	09/26/86	16:00	1,099.4		4.9	4590	21.2	0.0			803.0	100.00	38.4	4386	0.15	15200	<2	<2	680		253000	4290.0	
	10/30/86	10:45	1,088.4	1088	4.9	3210	21.6	0.0			730.0	96.70	32.7	4080	0.59	11500	<2	<2	700		232000	3390.0	
	10/30/86	10:45	1,088.4	1400	4.9	4185	19.8	0.0			726.0	95.90	30.5	4040	0.45	10300	<2	<2	540		234000	3590.0	
	10/30/86	11:55	1,088.4	2200	4.1	7140	20.6	0.0			1950.0	169.00				164000	12	<2	1670		510000	7000.0	
	07/31/87	13:25	1,021.2		5.4	3735	24.5	24.5			515.0	79.90	39.5	3300	0.18	4310	69	5	92		163000	1680.0	
	10/14/87	14:20	1,007.1	1007	4.0		17.6	0.0			0.5	21.40				1380	250	<1	130	70	54000	29.0	
	10/14/87	15:00	1,007.1	1057	3.8	1220	17.5	0.0			0.4	20.80	18.5	1315	0.19	840	260	<2	120	40	55200	31.0	
	10/14/87	15:40	1,007.1	1107	5.5		12.8	0.0			247.0	47.90				2780	120	<2	140	70	106000	888.0	
	10/14/87	16:00	1,007.1	1207	5.5		18.6	0.0			286.0	52.10				3080	110	<2	150	120	115000	1050.0	
	10/14/87	16:30	1,007.1	1507	5.4		18.3	0.0			285.0	52.40				3260	110	<2	140	90	114000	1040.0	
	01/27/88	10:30	993.2		4.3	2060	19.0	0.0			0.5	20.50	17.3	1253	0.94	1090	180	4	140	<40	50900	14.0	
	03/29/88	09:50	981.8		4.1	2020	19.5	0.0			0.3	22.70	19.5	1210	0.23	1070	144	2	172	<40	50700	18.0	
	05/31/88	12:44	970.7		4.2	2410	22.0	25.8			249.0	50.00	31.5	2353	0.07	1930	49	7	110		99900	14.0	
	05/31/88	13:10	970.7	1500	5.4	2660	21.3	62.3			504.0	74.10	35.9	3130	0.15	6420	17	<2	28		144000	1455.0	
	06/29/88	10:26	962.6		5.6	3820	22.2	39.1			410.0	68.60	38.7	2990	0.02	3900	19	9	130	190	125000	103.0	
	07/28/88	11:10	958.3		5.7	4260	24.5	43.8			403.0	65.80	38.8	3010	0.09	3880	84	120	120	1250	120000	141.0	
	09/29/88	10:30	949.2		5.6	4080	24.5	0.0			508.0	70.00	37.9	3210	1.06	4710	98	100	180	<40	144000	1126.0	
	10/27/88	11:15	945.6		5.6	4305	22.0	36.0			475.0	70.40	37.0	3280	0.33	3560	35	38	166	370	131000	237.0	
	11/30/88	11:25	942.0		5.3	2990	24.0	78.1			466.0	70.70	38.4	3210	0.04	4310	23	13	83	100	131000	59.0	
	02/27/89	11:28	930.8				24.0	100.5			454.0	66.10	37.1	3010	0.10	3610	40	<2	62	48	12100	24.0	
	03/30/89	11:30	917.5		5.9	4714	25.0	83.6			466.0	68.70	37.0	3400	0.15	3510	80	52	75	160	12200	54.0	
	04/26/89	11:27	925.1		5.6	4418	25.0	0.0			183.0	35.70	38.8	2430	0.13	970	100	17	90	60	95000	29.0	
	08/04/89	11:20	927.7		5.5	4320	25.0	49.0			532.0	82.00	41.3	4040	0.99	3020	50	2	97	120	13000	234.0	
	12/28/89	13:00	907.6		5.4	4240	24.5	0.0			486.0	72.41	45.4	3500	<0.06	3460	<5	<5	120	110	13800	2020.0	
	5/91				5.82	3681	24	65E			247E	44.9E		2870E		2030E	<1.4E	<7.7E	440E	16S	112000E	1310E	
	8/91				5.47	3718	25	84E			307E	55.4S		262E		1560E	<2.9E	<5.2E	116S	43E	105000E	489E	
	11/11/87	10:20	1,318.4		5.4	1150	15.5	208.9			28.6	118.00	39.1	1600	0.50	<30	54	<2	8	100	162000	198.0	<.1
	11/11/87	10:55	1,318.4	1400	5.4	1210	15.0	200.9			28.1	118.00	40.6	1640	0.33	50	61	<2	9	60	165000	193.0	0.1
	11/11/87	11:25	1,318.4	1500	4.6	1280	16.0	200.9			28.3	117.00	39.3	1620	0.50	<30	50	<2	6	<40	164000	203.0	<.1

Physical Parameters										Dissolved Concentration											
Site	Date	Time	SWL (mm/dd/yr)	Sample (ft)	pH	SC (UMHOS)	Temp (C)	Alkalinity (MG/L)	Fe (mg/l)	Mn (mg/l)	Cl (mg/l)	SO4 (mg/l)	NO3 (mg/l)	Al (ug/l)	Cd (ug/l)	Cr (ug/l)	Cu (ug/l)	Pb (ug/l)	Zn (ug/l)	As (ug/l)	Se (ug/l)
Lexington	02/29/88	10:00	1,307.3		6.0	2680	15.5	220.1	25.3	111.00	39.1	1576	0.78	<30	86	11	<2	<40	152000	152.0	
	03/31/88	13:55	1,302.3		6.2	2735	15.5	154.6	24.7	104.00	40.2	1570	0.39	<30	77	<2	7	60	144000	157.0	
	06/01/88	10:45	1,287.3		5.9	2895	17.0	231.4	25.4	96.20	40.8	1493	0.05	<30	54	2	<2		130000	153.0	
	07/29/88	10:10	1,279.3		5.8		17.0	255.3	24.3	90.60	41.8	1512	0.05	50	49	7	17	70	124000	191.0	
	04/05/90	10:00	1,214.0	1400	6.3	2555	14.0	151.7	6.1	106.00	41.7	1580	1.19	<40	328	<5	13	60	129000	4.3	<0.1
	04/05/90	10:30	1,214.0	1600	6.4	2555	15.0	0.0	8.0	106.00				<40	285	<5	8	50	123000	4.9	<0.1
	5/91				6.57	2714	9.8	142E	0.738 S	129E		1800 E		231 S	547 E	<7.7 E	267 S	1.8 E	215000 E	6.7 S	
	8/91				6.4	2525	16	161E	0.743 E	109 S		1540 E		396 E	378 E	14 E	178 S	4.3 E	150000 E	5 S	
	07/28/83	10:08	1,878.3		3.1	3265	17.5	0.0	150.0	42.90	37.3	2450	5.92	4780	170	32	11500		254000	113.0	
	10/15/83				4.6	2470	16.0	0.0	11.1	38.60	43.5	1900	0.96	2030	200	48	11700	100	140000	9.0	
Steward	04/26/84	14:15	1,402.0		5.0	2100	11.0	0.0	5.1	27.00				1720	140	23	12800		109000	27.5	
	07/26/84	10:08	1,333.5		5.2	2325	17.1	19.6	17.9	33.10	29.5	1520	0.18	2030	140	12	7680		110000	97.0	
	10/18/84	11:25	1,287.0		5.3	1480		51.8	8.8	17.30	33.3	1080	0.93	900	160	7	8530		77100	55.0	
	05/30/85	11:40	1,198.0		4.2	900	10.5	1.3	2.7	5.97	11.3	514	0.55	1280	89	<2	4680		37000	15.0	
	10/31/85	11:30	1,146.6		3.2	4000	14.5	0.0	58.3	27.00	32.0	1670	1.59	4920	200	<2	10000		126000	21.0	
	02/27/86	11:55	1,113.5		3.2	2070	16.0	0.0	20.7	21.40	32.7	1560	0.05	3910	140	<2	8050		93500	21.0	
	05/29/86	12:15	1,092.3		3.8	2590	18.2	0.0	27.6	22.20	45.9	1605	0.10	2800	150	<2	8230		88000	2.6	<.1
	06/26/86	10:40	1,087.6		5.5	1560	12.8	33.4	21.3	13.70	42.6	1258	0.04	390	140	6	5140		72100	68.0	0.2
	07/31/86	10:20	1,077.1		5.7	2320	15.5	61.0	8.4	10.60	41.3	1010	0.27	420	210	<2	8140		75200	57.0	
	09/26/86	11:20	1,059.3		5.8	1950	13.8	81.0	18.5	15.10	36.9	1176	0.09	270	120	<2	2400		71900	88.0	
	06/25/87	09:03	991.4		5.5	915		73.7	5.4	9.27	41.1	936	1.15	200	132	<2	4820		55600	39.0	
	05/31/88	15:00	934.4		5.9	2476	22.0	138.4	298.0	42.50	39.2	2610	0.06	1460	14	<2	510		93700	1666.0	
	06/29/88	13:25	928.9		5.5	3610	22.0	116.5	329.0	45.80	38.7	2650	0.08	2560	27	33	550	130	103000	1900.0	
	07/28/88	14:45	926.2		5.6	4410	22.4	89.9	334.0	46.10	38.6	2720	0.05	3770	120	160	490	1320	103000	2290.0	
	09/29/88	14:00	913.6		5.8	3670	23.0	37.2	261.0	39.40	38.9	2370	0.11	2130	58	81	360	80	90900	1628.0	
	10/27/88	14:50	909.8		5.2	2610	22.0	0.0	249.0	39.30				2160	15	<2	446	<40	87000	1602.0	
	11/30/88	14:20	905.7		5.5	2839	22.0	148.1	241.0	39.60	39.0	2360	0.04	1580	22	<2	220	70	87900	1537.0	
	02/27/89	14:04	895.5		5.7	4005	23.0	152.7	236.0	38.00	36.7	2310	0.05	920	40	5	280	55	81800	1520.0	
	03/30/89	13:47	891.9		5.7		22.0	118.5	209.0	38.40	40.1	2460	0.22	870	70	12	730	86	94000	1145.0	
	04/26/89	14:13	889.4		5.8	3454	23.0	25.7	183.0	35.60	37.7	2380	1.43	710	75	13	610	110	95400	1208.0	
	08/04/89	18:10	886.2		5.7	3500	23.0	0.0	196.0	41.40	39.6	2740	0.98	948	87	<2	1580	<40	104300	1528.0	
	12/28/89	14:05	873.1		5.6	3540	22.5	0.0	206.0	40.10	36.7	2650	<0.06	820	<5	<5	790	80	94300	1460.0	

Physical Parameters										Dissolved Concentration												
Site	Date	Time	SWL (FT)	Sample Depth (FT)	pH	FIELD			Alkalinity (M/G/L)	Fe (mg/l)	Mn (mg/l)	Cl (mg/l)	SO ₄ (mg/l)	NO ₃ (mg/l)	Al (ug/l)	Cd (ug/l)	Cr (ug/l)	Cu (ug/l)	Pb (ug/l)	Zn (ug/l)	As (ug/l)	Se (ug/l)
						SC (UMHOS)	Temp (C)	Altitude														
Steward	05/01/90	14:30	862.4		5.8	3410	24.0	113.2		189.0	37.15	36.4	2450	0.06	680	<5	<5	645	120	77800	1170.0	
	5/91				5.58	3139	22	48E		166E	58.9E		2130E		862E	150E	<7.7E	737E	1.8E	119000E	1410E	
	8/91				5.71	3212	NR	124E		178E	31.8S		216E		904E	80.2E	<5.2E	965E	4.4E	94500E	1380E	
Emma (West Camp System)	10/31/88	14:50	228.1		6.6	1740	15.0	296.1		12.9	20.80	37.1	641	0.11	<30	12	<2	8	<40	2190	161.0	
	04/07/89	17:30			6.7	1560	13.8	259.2		8.7	20.30	37.2	667	0.07	<30	6	<2	50	70	2780	147.0	
	08/08/89	14:45	230.0		6.7	1680	16.2	272.3		10.3	17.70	1.0	627	0.08	<30	<2	<2	3	<40	2200	126.0	
	5/91				6.76	1448	15.5	291E		7.94S	12.5E		552E		86S	13.4S	<7.7E	16S	1.4E	831E	118E	
	8/91				6.55	1534	16.5	259E		9.15E	19.5S		622E		263E	<2.9E	<5.2E	46.4S	2.8E	3290E	119E	
Travona	04/28/83	13:25	417.8		7.0	1270	10.0	245.2		1.3	2.15	41.4	372	3.80	1300	<2	2	24		81	97.0	
	10/13/83	15:15	423.1		6.7	1216	12.0	248.5		1.1	2.20	44.9	344	1.30	<30	<2	<2	15		41	80.0	
	02/16/84	12:10	387.6		6.6	1000	11.0	242.5		2.5	2.64	35.6	391	0.03	60	<2	<2	30		98	78.0	
	04/26/84		384.5		7.2	1150	8.0	0.0		2.0	2.49				<30	<2	<2	50		240	76.5	
	07/26/84	12:05	380.0		7.1	1248	15.2	265.7		1.8	2.64	33.2	352	1.73	<30	<2	<2	69		81	93.0	
	10/18/84	13:55	355.4		6.8	1120	10.4	257.5		3.0	3.35	41.6	365	10.70	40	<2	3	62		74	125.0	
	10/31/85	14:00	287.6		6.0	1250	11.3	272.3		2.3	3.39	40.0	381	0.15	<30	<2	<2	4		36	101.0	
	10/31/85	14:20	287.6		6.6	1200	10.5	271.5		3.1	3.45	40.1	380	0.12	<30	<2	<2	2		140	91.0	
	05/29/86	14:15	270.2		6.5	1110	14.5	285.4		1.6	3.43	39.9	335	0.07	<30	<2	<2	<2		55	74.7	<.1
	06/26/86				6.6	1180	14.0	270.7		2.3	3.45	41.5	375	0.04	<30	3	<2	7		230	96.0	0.1
	07/31/86	11:40	265.6		6.8	1120	13.8	273.1		1.7	3.54	38.3	349	3.04	<30	<2	<2	<2		<4	99.0	0.2
	09/26/86	14:20	257.0		6.5	1290	11.3	287.1		3.3	5.96	37.6	394	0.33	<30	<2	<2	<2		120	187.0	
	12/23/86	13:45	245.1		6.8	1525	11.0	0.0														
	01/27/87	13:15	240.9		6.2	1550	12.0	0.0														
	06/25/87	10:05	226.1		6.4	1330	14.0	240.6		8.7	28.30	35.7	624	0.14	<30	<2	<2	6		160	179.0	
	07/31/87	12:05	221.4		6.5	1250	12.0	258.4		8.8	28.80	34.7	573	0.62	<30	<2	<2	<2	<40	190	175.0	
	09/28/87		210.8		6.5	1290	13.0	247.7		8.2	26.00	35.1	602	0.02	<30	<2	<2	9	<40	93	177.0	
	10/30/87	15:20	203.2		6.6	870	13.0	238.5		8.2	25.70	34.3	614	0.93	<30	<2	<2	3	<40	120	150.0	
	02/27/88	15:30	193.7		6.5	1660	12.0	247.7		8.2	28.30	33.0	658	1.68	<30	<2	<2	<2	<40	63	138.0	
	03/29/88	15:25	193.4		6.6	1520	11.0	230.8		7.7	24.30	35.7	615	0.07	<30	<2	<2	<2	<40	113	164.0	
	05/31/88	16:20			6.5	1778	12.0	298.5		7.6	20.10	35.8	569	0.05	<30	<2	<2	6		160	122.0	
	06/03/88	14:50	197.0	197	6.3	1420	13.0	275.6		7.6	19.40	35.8	573	0.17	<30	<2	<2	10		28	170.0	
	06/03/88	14:20	197.0	300	6.3	1420	13.0	250.2		7.4	19.10	36.4	580	0.17	<30	<2	<2	2		28	175.0	

Physical Parameters									Dissolved Concentration													
Site	Date (mm/dd/yy)	Time (Hours)	SWL (Ft)	Sample Depth	FIELD				Fe (mg/l)	Mn (mg/l)	Cl (mg/l)	SO4 (mg/l)	NO3 (mg/l)	Al (ug/l)	Cd (ug/l)	Cr (ug/l)	Cu (ug/l)	Pb (ug/l)	Zn (ug/l)	As (ug/l)	Se (ug/l)	
					SC (UMHOS)	Temp (C)	Alkalinity (MG/L)															
Travona	06/03/88	13:55	197.0	500	6.1	1550	13.0	255.9	7.7	19.40	36.7	585	0.12	<30	<2	<2	9		38	185.0		
	06/03/88	15:25	197.0	800	6.7	1490	13.0	269.8	8.4	21.10	35.8	596	0.06	<30	<2	<2	2		9	209.0		
	06/29/88	15:20	197.6		6.1	1310	14.0	247.7	7.0	18.50	36.3	592	0.03	<30	<2	<2	5	<40	120	151.0		
	07/28/88	16:10	195.4		6.8	1700	15.4	254.3	6.5	16.50	37.0	570	0.05	<30	<2	<2	5	<40	93	158.0		
	09/28/88	15:30	185.8		6.9	1510	13.0	245.0	6.7	16.20	37.1	532	0.16	<30	<2	<2	<2	<40	71	178.0		
	10/27/88	16:10	182.5		6.7	1519	12.0	0.0	6.6	16.30				<30	<2	<2	4	<40	83	162.0		
	11/30/88	16:00	180.3		6.4	1298	12.5	290.3	7.0	17.50	35.9	528	0.04	<30	<2	<2	2	<40	9	143.0		
	11/30/88	16:30	180.3		6.5	1604	13.0	287.9	6.8	17.30	36.6	525	0.02	<30	<2	<2	2	<40	17	144.0		
	01/29/89	07:00			6.8	1424	12.4	274.8	6.9	17.30	34.6	537	0.03	<30	2	<2	<2	15	7	110.0		
	04/07/89	18:55	200.0		6.9	1700	11.3	249.3	1.5	11.70	38.1	506	0.07	<30	<2	<2	2	<40	100	82.0		
	04/07/89	19:20	200.0		6.9	1361	11.2	253.4	4.3	11.50	37.4	481	0.06	<30	<2	<2	<2	<40	6	134.0		
	04/26/89	15:27	192.1		5.8	1471	23.5	251.8	4.3	12.10	36.2	494	0.47	<30	<2	<2	4	<40	590	143.0		
	08/09/89	20:00	184.3		6.9	1126	13.0	264.2	4.6	12.84	37.7	495	0.05	<40	<5	<5	<4	<40	110	106.0		
	12/21/89								2.8	11.10							5	1	30	100		
	12/29/89	14:40	174.0	240	6.6	1420	12.0	255.9	5.6	14.36	35.0	514	1.66	38	<5	<5	8	<50	25	180.0		
	1/30/90								7.1	15.70		536			0.1		8	3	15	150		
	2/27/90								6.4	14.10		511			0.05		45	1	29	160		
	3/5/90								5.8	12.40		517			0.19		32	4	307	143		
	4/25/90								5.9	12.80		504			0.16		4	2	59	148		
	7/23/90								5.0	10.50		469			1		4	1	29	146		
	8/24/90								4.6	9.47		462			1		4	1	23	133		
	9/28/90								4.5	8.95		440			1		4	1	5	156		
	11/29/90								4.3	9.50		447			1.5		7	1	30	126		
12/26/90								3.6	8.89		456			1.5		21	1	14	112			
8/28/91								4.7	8.79		438			438		1	1	19	149			
9/26/91								4.1	8.19		472			1.5		1	1	7	158			
10/31/91								4.4	9.17		468			1.5		1	1	6	167			
12/26/91								5.0	9.32		480			1		1	1	15	134			
3/31/92								0.0	8.12		488					15	1	12	11			
8/26/92								5.1	10.40							2	1	49	187			
9/28/92								5.3	10.20							2	1	20	268			
10/29/92								4.4	8.49							43	4	60	120			
2/16/93								4.5	8.85							1	1	24	189			

Physical Parameters										Dissolved Concentration												
Site	Date (mm/dd/yy)	Time	SWL (FT)	Sample Depth	FIELD			Temp (C)	Alkalinity (MG/L)	Fe (mg/l)	Mn (mg/l)	Cl (mg/l)	SO4 (mg/l)	NO3 (mg/l)	Al (ug/l)	Cd (ug/l)	Cr (ug/l)	Cu (ug/l)	Pb (ug/l)	Zn (ug/l)	As (ug/l)	Se (ug/l)
					SC	pH	Depth															
Travona	3/18/93									4.2	8.78							1	1	11	153	
	7/14/93									3.9	8.16							4	1	7	177	
	8/12/93									3.4	6.67							1	5	10	140	
	9/23/93									2.0	8.17							1	2	14	77	
	10/23/93									3.7	7.64							2	2	24	178	
Margot Ann (Outer Camp System)	11/11/87	14:45	105.6	105.6	425	7.4		8.5	102.8	0.4	2.02	19.5	288	0.34	<30	<2	<2	3	<40	330	0.9	<1
	11/11/87	15:04	105.6	150	420	7.7		8.3	102.4	0.6	1.43	18.5	282	0.50	<30	<2	<2	4	<40	64	2.9	<1
	11/11/87	15:10	105.6	200	410	7.7		8.0	103.3	0.4	1.40	18.4	282	0.14	<30	<2	<2	3	<40	15	1.8	<1
	11/11/87	15:25	105.6	250	272	7.9		25.0	110.9	0.6	1.86	17.7	298	0.36	<30	<2	<2	<2	<40	9	1.3	<1
	02/29/88	11:15	106.0		615	6.6		8.0	100.1	0.4	1.36	18.4	278	0.06	80	<2	6	6	40	5	2.0	
	06/01/88	11:20	113.1		598	6.7		9.0	135.7	0.4	1.62	37.8	268	0.12	<30	<2	<2	6	40	69	2.4	
	07/29/88	11:36	109.5		820	6.9		11.0	121.1	0.5	1.94	35.7	283	0.15	<30	2	<2	6	40	280	2.1	
	08/10/89	15:45	118.8		840	7.4		11.9	181.9	0.1	1.47	28.8	280	0.14	80	<2	15	<2	<40	10	0.6	
	04/05/90	11:40	118.5	250	890	7.1		7.0	189.5	0.1	2.28	25.5	266	0.06	<40	<5	<5	<4	<50	61	0.6	
	5/91				814	6.88		9.1	198E	0.104S	1.97E		179E		66S	6.9S	<7.7E	10S	<82E	11E	5.2S	
	8/91				883	7.18		9.5	204E	0.187S	2.26S		225E		116E	<2.9E	<5.2E	29.3S	1.3E	35.9S	4.8S	
	04/02/92				826	7.3		11.4	204.14	0.097	1.78	25	247	<0.1	<100	<1.0	<6.0	<2.0	<0.4	<3.0	<1.0	
	04/02/92				826	7.3		11.4	203.73	0.102	1.87	24.7	248	<0.1	<100	<1.0	<6.0	<2.0	<0.4	<3.0	<1.0	
Missoula	02/04/88	10:40	312.0	315	7.1			9.0	378.9	3.0	12.50	48.5	1276	0.05	<30	<2	<2	<2	<40	35	1.0	
	02/04/88	10:50	312.0	350	7.2			9.0	383.0	3.0	12.70	48.2	1274	0.03	<30	<2	<2	<2	<40	19	0.6	
	02/04/88	11:00	312.0	400	7.3			10.0	380.6	3.0	12.60	47.7	1272	0.04	<30	<2	<2	<2	<40	8	0.9	
	02/04/88	11:20	312.0	490	7.3			10.0	382.2	3.0	12.60	49.6	1281	0.06	<30	<2	<2	<2	<40	<3	0.3	
	06/01/88	09:58	316.6		1942	7.8		10.0	365.8	3.3	10.90	49.6	1245	0.03	<30	<2	<2	18		30	2.6	
	07/29/88	09:30	312.5		2180	6.6		11.0	360.1	2.4	10.30	51.0	1270	0.13	<30	<2	<2	8	<40	44	2.0	
	08/09/89	15:50	304.6		1370	7.3		12.1	164.0	0.4	7.37	15.7	518	5.27	<30	<2	<2	26	<40	2440	2.6	
Orphan Boy	01/27/87	14:00	124.4		2400	6.4		24.0	0.0	0.3	8.84	14.5	702	0.13	<30	<2	<2	12		10	90.0	0.1
	05/28/87	12:40	127.5			6.5		17.6		0.3	8.18				<30	<2	<2	<2		22	18.0	
	06/25/87	11:25	125.5			6.6				0.6	7.67	14.5	638	0.06	<30	<2	<2	<2		29	12.0	
	05/31/88	17:10	124.0		1701	6.3		25.0	770.1	0.6	8.04	14.5	648	0.07	<30	<2	<2	<2		46	175.0	
	06/29/88	17:10	124.1		2210	6.3		18.2	750.5	0.5	8.04	14.5	648	0.07	<30	<2	<2	<2				

				Physical Parameters							Dissolved Concentration						
Site	Screened Intervals (ft.)	Well Depth (ft.)	Depth to Competent Bedrock (ft.)	Date (mm/dd/yy)	Time (hours)	SWL (ft.)	Sample Depth (ft.)	Field pH	Field SC (umhos)	Temp (C)	Alkalinity (mg/l)	Fe (mg/l)	Mn (mg/l)	Cl (mg/l)	SO4 (mg/l)	NO3 (mg/l)	
Well A	680-700	745	530	05/91		537.0	710	6.46	1698	19.5	42.0	15.2	4.17		980	<0.5R	
	09/10/91			15:38	568.0	710	6.50	1724	18.8	57.0	15.20	4.55	19.6	942.0	0.15		
	5/91				428.5		6.13	1690	18.6	58.8	17.20	5.00	17.5	900.0	<0.5R		
Well B		643	233	01/28/92	10:30			7.73	1190	15.3	99.2	0.84	1.62	30.4	533.3	<1	
	date(1992)			17:59	317.4		7.83	1200	14.5	43.2	0.15	1.41	29.7	579.8	<1		
	04/92			17:59	317.4	570	7.83	1198	14.5	43.21	0.154	1.41	29.7	580	<0.1		
	628-638			5/20/93								1380					
Well C	755-795	800	725	08/29/94	13:31	295.8		6.42	1406	16.4	102.0	1.80	2.39	27.5	650.0	<0.5	
	5/91				568.0	775	5.84	683	17.8	25.0	9.5	1.67		313	<0.5R		
	05/29/91			10:30		5.84	680	17.8	24.6	9.61	1.72	3.5	336.0	<0.3			
Well D-1		635	388	8/91		568.0	775	6.02	738	17.2	25.0	9.6	1.67		376	<0.5R	
	08/25/94			16:44	494.1		5.88	690	18.2	34.0	5.78	1.77	4.0	300.0	<0.5		
	04/14/92				560.1	620	6.52	623	15.8	33.5	4.1	1.35	3.7	274	<0.1		
Well D-2	600-635	775	422	04/14/92	12:55	560.1		6.52	625	15.8	33.5	4.10	1.35	3.7	273.6	<1	
	08/30/94			12:57	501.2		5.87	680	15.9	24.2	12.80	1.70	2.5	300.0	<1		
	05/91				575.0	715	6.56	1233	16.0	31.0	19.0	3.37		598	<0.5R		
Well E	600-670	355	242	05/31/91	18:45	578.6		6.56	1195	16.0	26.1	19.70	3.26	5.8	652.1	<0.3	
	08/91				575.0	715	6.47	1198	17.1	24.0	17.6	2.32		647	<0.5R		
	05/28/92			20:38		665	6.59	1175	15.9	27.8	25.91	3.21	11.4	654.3	0.85		
Well F	760-770	639	308	05/29/92				6.59	1173	15.9	27.8	25.9	3.21	11.4	654	0.85	
	08/31/94			17:05	490.2		9.25	800	12.2	38.1	0.01	0.63	17.5	350.0	<1		
	05/91				174.2	310	6.79	1406	14.1	30.0	2.8	1.70		390	<0.5R		
Well G	270-290	355	242	08/91		174.2	310	6.82	767	14.5	42.0	3.1	1.69		404	<0.5R	
	05/29/92			18:30	170.6	280	6.76	787	15	33.9	1.94	1.43	5.8	357	<0.1		
	05/29/92			18:30	170.6	280	6.76	787	15	34.1	1.91	1.41	5.8	353	<0.1		
Well H	614-634	639	308	08/25/94	17:15	171.5		6.38	790	13.9	32.4	1.70	1.39	5.0	350.0	<0.5	
	07/31/92			12:30	32.4		7.68	1320	16.8	131.2	0.74	0.42	21.7	775.0	<25		
	04/19/93			14:00	34.9		7.59	1585	14.2	165.7	0.85	0.55	22.1	708.0	<0.2		
Well I		639	308	05/19/93								887					
	05/19/93			13:45	33.9		7.25	1620	16.4	63.3	0.64	0.61	17.5	750.0	<0.5		
	08/24/94																
Well J		639	308	05/91			220	7.04	926	10.0	191.0	0.1	0.08		242	1.2R	
	08/91					220	6.82	988	10.9	190.0	0.0	0.05		229	1.65R		
	03/30/92					220	6.79	988.5	12	191.1	0.006	0.029	57	248	0		
Parrott				05/91				7.33	1214	10.5	282.0	0.0	0.39		403	0.9R	
	08/91						6.93	1410	11.0	217.0	0.1	0.49		542	<0.5R		

Site	Date (mm/dd/yy)	Dissolved Concentration																	
		Al (ug/l)	Cd (ug/l)	Cr (ug/l)	Cu (ug/l)	Pb (ug/l)	Zn (ug/l)	As (ug/l)	Se (ug/l)	B (ug/l)	Br (ug/l)	Li (ug/l)	Mo (ug/l)	Ni (ug/l)	Ag (ug/l)	Sr (ug/l)	Ti (ug/l)	V (ug/l)	Zr (ug/l)
Well A	05/91	547	3.7	<7.7	129	<.82	372	96.2		<100		102	<40		<6	750			
	09/10/91	<100	<6	<10	<6	<100	128	74.0											
	5/91	108	3	<5.2	24	3	146	51.7		<80		113	<10		<1	701			
	08/24/94	<30	<2	2	<2	<2	112	55.6											
Well B	01/28/92	<50	<6	<6	<6	<50	62	16.7		<100		16	<40		<6	600			
	date(1992)	<100	<1	8	<2	<1	64	13.0		120		25	3		16	585			
	04/92	<100	<1.0	8	<2.0	<0.4	64	13		120	134	25	3	<20.0	16	585	53	61	22
	5/20/93	38.1	2.3	2.8	1.2	1		6.9						718000					
Well C	08/29/94	<30	<2	<2	<2	<2	6	7.9		<80		30	<10		<1	766			
	5/91	589	0	<7.7	15	1	2660	5.1R		<100		13	<40		<6	356			
Well D-1	05/29/91	460	<6	<6	<6	<50	2630	2.0											
	8/91	726	3		19	3	1840	6.1		<80		31	<10		<1	326			
Well D-2	08/25/94	367	<2	2	<2	<2	1180	1.6											
	04/14/92	<100	<1.0	9	<2.0	<0.4	1983	10		<100	<100	23	<1.0	<20.0	16	20.1	35	62	21
	04/14/92	<100	<1	9	<2	<2	1983	10.0		<100		23	<1		16	20.1			
	08/30/94	<30	<2	<2	3	<2	935	11.8		<80		25	<10		<1	145			
Well E	05/91	121	1	<7.7	16	1	1690	17.7		<100		33	<40		<6	327			
	05/31/91	<80	<6	<6	<6	<50	1580	10.0											
	08/91	70.8	<2.9	<5.2	16	7	1900	7.9		<100		44	<1		50	231	42	78	77
	05/28/92	200	<1	40	<2	1.2	1691	38.0		<100	<100	44	<1.0	<20.0	50	231			
Well F	05/29/92	200	<1.0	40	<2.0	1.2	1691	38		<100	<100	200	9.4		<1	952			
	08/31/94	<30	<2	<2	2	<2	2	3.4		<80									
Well G	05/91	29	3	<7.7	7	<.82	27	32.5											
	08/91	184	<2.9	<5.2	36	5	72	38.4											
	05/29/92	<100	<1.0	10	2	1.8	23	32		<100	<100	68	1	<20.0	17	631	43	56	29
	05/29/92	150	<1.0	21	<2.0	1.8	19	32		<100	<100	72	1	<20.0	29	630	45	58	44
Well H	08/25/94	<30	<2	<2	<2	<2	16	27.0		<80		81	<10		<1	727			
	07/31/92	<20	<2	<2	<2	2.8	47	242.0		375		965	<20		<1	4500			
	04/19/93	<30	<2	<2	<2	<2	125	240.0		412		1038	<10		<1	4425			
	05/19/93	24.4	2.3	2.8	1.2	1.5		254											
Well I	05/19/93	27.3	2.3	2.8	1.2	1.5		232											
	08/24/94	<30	<2	3	<2	<2	101	273.8		419		965	<10		<1	4331			
	05/91	73	8	<7.7	13	3	129	4.2											
	08/91	151	<2.9	<5.2	32	6	554	3.8											
Well J	03/30/92	<100	1	<6.0	2	2.2	99	2		<100	252	13	<1	<20	<6	504	43	19	<8
	05/91	44	219	<7.7	319	47	1670	7.4											
Parrot	08/91	320	236	<5.2	327	50	2150	3.6											

Sources: Canonic, 1992a.

MBMG, 1992 and 1994. Analytical data sheets for Bedrock Monitoring, Ted Duaine.

Canonic, 1994.

Appendix IIC. Bedrock Groundwater Quality Data: NRDA Bedrock Monitoring Results.

Table 1

Analytical Results (mg/l) for the NRDA Bedrock Sampling Locations

Sample Designation	Location	pH	Sulfate	Arsenic	Cadmium	Copper	Iron	Manganese	Molybdenum	Lead	Zinc
Well 1	Trip Blank	NA	0.0	.001 U	.001 U	.002 U	.003 U	.002 U	.001 U	.0004 U	.003 U
Well 2	Hebgen	6.78	247.5	0.002	0.001	0.002	0.008	0.029	.001 U	0.022	0.099
Well 3	Rinseate Blank-1	5.27	.1 U	.001 U	.001 U	0.002	.003 U	.002 U	.001 U	.0004 U	0.005
Well 4	Trip Blank	NA	NA	.001 U	.001 U	.002 U	.003 U	.002 U	.001 U	.0004 U	.003 U
Well 5	Marget Ann	7.35	246.7	.001 U	.001 U	.002 U	0.097	1.780	.001 U	.0004 U	.003 U
Well 6	Marget Ann-Dup	7.38	249.7	.001 U	.001 U	.002 U	0.102	1.870	.001 U	.0004 U	.003 U
Well 7	Trip Blank	NA	NA	.001 U	.001 U	.002 U	.003 U	.002 U	.001 U	.0004 U	0.006
Well 8	Well B	7.89	579.8	0.013	.001 U	.002 U	0.154	1.410	0.003	.0004 U	0.064
Well 9	Well D-1	6.62	273.6	0.010	.001 U	.002 U	4.100	1.350	.001 U	.0004 U	1.983
Well 10	Rinseate Sample-	7.38	5.5	0.001	.001 U	0.003	0.003	.002 U	.001 U	.0004 U	0.007
Well 11	Well E	6.82	356.5	0.032	.001 U	0.002	1.940	1.430	0.001	0.0018	0.023
Well 12	Well E-dup	6.85	353.0	0.032	.001 U	.002 U	1.910	1.410	0.001	0.0018	0.019
Well 13	Well D-2	6.52	654.3	0.038	.001 U	.002 U	25.910	3.210	.001 U	0.0012	1.691
Well 14	Bottle Blank	NA	0.0	.001 U	.001 U	.002 U	.003 U	.002 U	.001 U	.0004 U	.003 U
Well 15	Filter Blank	NA	0.0	.001 U	.001 U	.002 U	.1 U	.002 U	.001 U	.0004 U	0.003

U: Below method detection limit

NA: Not Analyzed

Table 2

Analytical Results (mg/l) for Bedrock Sampling Locations

MCL	Hebgen Park			Margot Ann			Well A		Well B
	May 91	Sept 91	Mar 92	May 91	Sept 91	Apr 92	May 91	Sept 91	Apr 92
Arsenic	.0042 S	.0038 S	0.002	.0052 S	.0048 S	.001 U	.0962 E	.0517 S	0.013
Cadmium	.008 S	.0029 UE	0.001	.0069 S	.0029 UE	.001 U	.0037 S	.0028 UE	.001 U
Copper	.013 S	.0318 S	0.002	.01 S	.0283 S	.002 U	.129 S	.024 S	.002 U
Iron	.068 S	.0477 S	0.006	.104 S	.187 S	.097	15.2 S	13.3 E	0.154
Manganese	.078 S	.0451 S	0.029	1.97 E	2.26 S	1.78	4.17 E	3.88 E	1.410
Molybdenum	NA	NA	.001 U	NA	NA	.001 U	NA	NA	0.003
Lead	.0031 E	.0061 E	0.002	.00082 UE	.0013 E	.0004 U	.00082 UE	.0028 E	.0004 U
Zinc	.129 E	.554 E	0.099	.011 E	.0359 S	.0003 U	.372 E	.146 S	0.084
Sulfate	242.0 E	229.0 E	247.5	179.0 E	225.0 E	246.7	980.0 E	892.0 E	579.8
pH	7.04	6.82	6.78	6.88	7.18	7.35	6.46	6.50	7.89

MCL	Well C		Well D1		Well D2		Well E	
	May 91	Sept 91	Apr 92	May 91	Aug 91	May 92	May 91	Sept 91
Arsenic	.0051 R	.0061 S	0.010	.0177 E	.0079 S	0.038	.0325 E	.0384 E
Cadmium	.00044 E	.0029 UE	.001 U	.00055 E	.0029 UE	.001 U	.0027 S	.0029 UE
Copper	.015 S	.0191 S	.002 U	.018 S	.0158 S	.002 U	.007 S	.0355 S
Iron	9.46 S	9.64 E	4.10	19.0 S	17.6 E	25.91	2.79 S	3.05 E
Manganese	1.67 E	1.67 S	1.35	3.37 E	2.32 S	3.21	1.7 E	1.69 S
Molybdenum	NA	NA	.001 U	NA	NA	.001 U	NA	NA
Lead	.0011 E	.0029 E	.0004 U	.00069 E	.0073 E	0.0012	.00082 UE	.0047 E
Zinc	2.66 E	1.84 E	1.983	1.69 E	1.9 E	1.691	.027 E	.0723 S
Sulfate	313.0 E	376.0 E	273.6	598.0 E	647.0 E	654.3	390.0 E	404.0 E
pH	5.84	6.02	6.62	6.56	6.47	6.52	6.79	6.82

Data not validated for 1992 sampling event

E = Enforcement quality data

S = Screening quality data

R = Rejected data

U = Below method detection limit

NA = Not Available for Data

(a) Primary maximum contaminant levels (MCLs), July 1, 1991, (CFR 40 Sections 141.11 and 143.3)

(b) Secondary EPA maximum contaminant levels (MCLs), July 1, 1991, (CFR 40 Sections 141.11 and 143.3)

Data Sources:

ARCO, 1992a. Preliminary Remedial Investigation Report for The Butte Mine Flooding Operable Unit
Remedial Investigation/Feasibility Study. Prepared by Canonle Environmental Services Corp.

MBMG, 1992. Analytical data sheets for the 1992 Sampling Event

Appendix IID. Bedrock Aquifer Baseline Water Quality Data.

Well #	Date	Depth (ft)	Aquifer	Weathered Competent	Field SC umhos/cm	Field pH	mg/l		
							Ca Calcium	Mg Magnesium	Na Sodium
BMW - 11B BMW - 5B BMW - 11B BMW - 13B	04/20/90	38.7-58.7	Bedrock	Weathered	1080	7.3	123	30.3	61.9
	?	37.5-57.5	Bedrock	Weathered					
	04/20/90	55-75	Bedrock	Weathered	1271	7.3	98	27.1	142
	04/20/90	45-65	Bedrock	Weathered	900	7.0	112	27.1	58.2
DW - 125	01/18/85	16-31	Bedrock	Weathered	1040	7.0	138	31.8	39
DW - 128	01/16/85	35-65	Bedrock	Weathered	435	6.8	64	13.4	16.6
	01/16/85	35-65	Bedrock	Weathered	435	6.8	62.2	13.1	17.2
	01/07/85	40-80	Bedrock	Weathered	785	7.0	112	21.4	26.7
Hall	09/19/85	140	Bedrock	Weath/Unweath		7.06	28.9	4.4	10.6
Scott	11/06/80	460	Bedrock	Unweathered		7.43	75.7	17	12.5
Tarkelson	07/14/80	100	Bedrock	Unweathered		7.83	32	8.7	21.1
Johnson	05/20/92	240	Bedrock	Unweathered		7.1	76	15.1	11.7
Hebgen Pk	03/30/92	140-300	Bedrock	Weathered	999	6.79	123	30.5	38.6
	May 1991	(sample depth = 75')	Bedrock	Weathered	926	7.04	115	30.2	36.6
	Sept 1991		Bedrock	Weathered	988	6.82	109	28.8	32.1
	May 1991	680-700	Bedrock	Competent	1698	6.46	165	4.17	108
Well A	Aug 1991	720-740	Bedrock		1724	6.5	164	3.88	114
	9/10/91						198.0	52.4	126.0
	8/24/94				1690	6.13	204.9	56.3	118.0
	08/27/92	565-575	Bedrock	Competent	1198	7.83	145	37.7	62.5
Well B	1/28/92				1190	7.73	150.0	38.7	65.6
	4/20/93				1365	7.25	176.0	47.6	66.8
	8/29/94				1406	6.42	200.0	52.2	66.0
	05/20/93				1330	7.25	172	46.9	61.9
Well C	May 1991	755-795	Bedrock	Competent	683	5.84	83.2	16.6	22.8
	Sept 1991		Bedrock		738	6.02	86.2	16.9	22.9
	5/29/91				680	5.84	86.3	17.1	24.5
	8/25/94				690	5.88	90.4	17.7	25.6
Well D-1	04/14/92	610-630	Bedrock	Competent	623	6.52	65.5	19.1	18.8
	8/30/94				680	5.87	74.9	25.7	22.9

Appendix IID. Bedrock Aquifer Baseline Water Quality Data.

IID-2

Well #	Date	mg/l						ug/l				
		K Potassium	Cl Chloride	HCO3 Bicarbonate	CO3 Carbonate	CaCO3 Tot Alk	Al Aluminum	Sb Antimony	As Arsenic	Be Beryllium		
BMW –1B	04/20/90	7.79	42			240	<22	<21	4.8	<1.0		
BMW –5B	?											
BMW –11B	04/20/90	4.49	37			160	<22	<21	5.2	<1.0		
BMW –13B	04/20/90	6.28	29			170	24.5	<21	3	<1.0		
DW –125	01/18/85	5.2	26.5			260			<4.6			
DW –128	01/16/85	2.3	6.5			115			<6.5			
	01/16/85	2.1	7			117			<6.5			
DW –129	01/07/85	5.1	57.3			171			<5.3			
Hall	09/19/85	1.6	NA	78.1					0.4			
Scott	11/06/80	3.1	NA	164					1			
Tarkelson	07/14/80	1.9	NA	117					NA			
Johnson	05/20/92	4.1	NA	77.6					0.5			
Hiebgen Pk	03/30/92	6.7	57	233	0		<100		2			
	May 1991	6.89	NA			191	73		4.2			
	Sept 1991	6.51	NA			190	151		3.8			
Well A	May 1991	19.9	NA			42	547		96.2			
	Aug 1991	20.6	NA			57	108		51.7			
	9/10/91	21.5	19.6	72.2	0.0		<100		74.0	NA		
	8/24/94	23.3	17.5	71.7	0.0		<30		55.6	6		
Well B	08/27/92	9.9	29.7	52.7	0		<100		13			
	1/28/92	8.6	30.4	121.0	0.0		<50		16.7	NA		
	4/20/93	10.8	28	127.0	0.0		<30		7.6	<2		
	8/29/94	10.4	27.5	124.4	0.0		<30		7.9	NA		
	05/20/93	10.1	26	97	20		38.1		6.9			
Well C	May 1991	9.37	NA			25	589		R			
	Sept 1991	9.66	NA			25	726		6.1			
	5/29/91	10.0	3.5	30.0	0.0		460		2.0	NA		
	8/25/94	12.2	4	41.5	0.0		367		1.6	<2		
Well D –1	04/14/92	10.4	3.7	40.8	0		<100		10			
	8/30/94	11.9	2.5	29.5	0.0		<30		11.8	NA		

Appendix IID. Bedrock Aquifer Baseline Water Quality Data.

IID-3

Well #	Date	ug/l									
		Cd Cadmium	Cr Chromium	Cu Copper	Fe Iron	Pb Lead	Mn Manganese	Ni Nickel	Ag Silver		
BMW -11B BMW -5B BMW -11B BMW -13B	04/20/90	0.08	<8.0	<4.0	<5	<0.5	<2	<1.3	<0.1		
	?	<5		<25	<100	<5					
	04/20/90	0.17	<8.0	<4.0	<5	0.6	<2	<1.3	<0.1R		
	04/20/90	0.36	<8.0	<4.0	<5	<0.5	218	<1.3	<0.1		
DW -125 DW -128 DW -129	01/18/85	<1.1		<40	<31	<4.3					
	01/16/85	<0.8		<40	72	<8.9					
	01/16/85	<0.8		<40	81	<8.9					
	01/07/85	<0.5		<40	<31	1.1					
Hall Scott Tarkelson Johnson	09/19/85	<2.0		2	<2.0	NA	1				
	11/06/80	<10.0		110	65	<40	11				
	07/14/80	NA		NA	40	NA	4				
	05/20/92	<6.0		<6.0	11	<1.0	<2.0				
Hebgen Pk	03/30/92	1	<6	2	6	2.2	29	<20	<6		
	May 1991	8	7.7	13	68	3.1	78	19	18		
	Sept 1991	<2.9	5.2	31.8	31.8	6.1	45.1	37.6	<2.9		
Well A	May 1991	3.7	<7.7	129	15200	<0.82	4170	64.5	12		
	Aug 1991	<2.8	<5.2	24	13300	2.8	3880	38	<2.9		
	9/10/91	<6	<10	<6	15.2	<100	4.55		<6		
	8/24/94	<2	2	<2	17.2	<2	5		<1		
Well B	08/27/92	<1	8	<2	154	<0.4	1410	<20	16		
	1/28/92	<6	<6	<6	0.84	<50	1.62		<6		
	4/20/93	<2	<2	<2	1.32	<2	2.12		<1		
	8/29/94	<2	<2	<2	1.8	<2	2.39		<1		
Well C	05/20/93	2.3	2.8	1.2	1380	1	2070	8.8	2.4		
	May 1991	0.4	<7.7	15	9460	1.1	1670	54	25		
	Sept 1991	<2.9	<5.2	19.1	9640	2.9	1670	45.1	3.5		
	5/29/91	<6	<6	<6	9.61	<50	1.72		<6		
Well D-1	8/25/94	<2	2	<2	5.78	<2	1.77		<1		
	04/14/92	<1	9	<2	4100	<0.4	1350	<20	16		
	8/30/94	<2	<2	3	12.8	<2	1.7		<1		

Appendix IID. Bedrock Aquifer Baseline Water Quality Data.

IID-4

Well #	Date	mg/l SO ₄ Sulfate	ug/l				Reference
			Tl Thallium	V Vanadium	Zn Zinc	Zr Zirconium	
BMW-11B	04/20/90	190	<2.0	4.7	10		1
BMW-5B	?	302			<20		1
BMW-11B	04/20/90	340	<2.0	<3.0	18		1
BMW-13B	04/20/90	290	<2.0	<3.0	438		1
DW-125	01/18/85	265			<27		2
DW-128	01/16/85	123			70		2
	01/16/85	130			68		2
DW-129	01/07/85	184			110		2
Hall	09/19/85	36.9			11		
Scott	11/06/80	129			2400		
Tarkelson	07/14/80	55.2			NA		
Johnson	05/20/92	27.9			<8.0		
Hefgen Pk	03/30/92	248		19	99	<8	5
	May 1991	242			129		6
	Sept 1991	229			554		6
Well A	May 1991	980			372		6
	Aug 1991	892			146		6
	9/10/91	942			128		5
	8/24/94	900			112		5
Well B	08/27/92	580		61	64	22	5
	1/28/92	533.3			62		5
	4/20/93	625			8		5
	8/29/94	650			6		5
	05/20/93	640			9.9		6
Well C	May 1991	313			2660		6
	Sept 1991	376			1840		6
	5/29/91	336			2630		5
	8/25/94	300			1180		5
Well D-1	04/14/92	273.6		62	1983	21	5
	8/30/94	300			935		5

Appendix IID. Bedrock Aquifer Baseline Water Quality Data.

IID-5

Well #	Date	Depth (ft)	Aquifer	Weathered Competent	Field SC umhos/cm	Field pH	mg/l		
							Ca Calcium	Mg Magnesium	Na Sodium
Well D-2	05/29/92	660-670	Bedrock	Competent	1173	6.59	139	47.1	35.9
	May 1991		Bedrock		1233	6.56	140	46.5	37.5
	5/31/91				1195	6.56	139.0	47.4	37.8
	Aug 1991		Bedrock		1198	6.47	127	43.9	31.1
	8/31/94				800	9.25	76.1	17.4	58.2
Well E	05/29/92	270-290	Bedrock	Competent	787	6.76	85.4	24.8	26.9
	05/29/92	(sample depth=260')	Bedrock		787	6.76	86	24.6	26.5
	May 1991		Bedrock		1406	6.79	82	27.4	27.1
	8/25/94				790	6.38	93.1	27.0	29.0
	Sept 1991		Bedrock		767	6.82	86.7	25.6	25.7
Well F	7/31/92				1320	7.68	190.0	19.9	179.0
	4/19/93				1585	7.59	182.0	18.5	178.0
	5/19/93				1545	7.59	170.0	17.9	169.0
	5/19/93				1545	7.59	153	15.9	144
	8/24/94				1620	7.25	196.9	19.6	173.0
93-69	07/19/90				1040	7.19	167	30.6	21
93-70	?				685	7.75		15.7	23.2
93-73	11/16/89				800	7.45	117	29.2	45
	?				666.8	7.35		22.8	25.6
93-83	11/01/88				1527		206	58.8	31.5
25 CAD	09/04/68	?	Bedrock	Weathered	296	7.58	30	10	15.3
36 ADA	09/04/68	?	Bedrock	Weathered	284	6.75	31	8.6	11.7
31 CCB	08/26/66	?	Bedrock	Weathered	307	7.95	34	11.7	6.5
06 BBB	08/26/66	Spring	Bedrock	Weathered	345	8	40	8.6	6.4
06 CBD	08/24/66	Spring	Bedrock	Weathered	300	7.85	30	8.6	6.2
27 CAD	07/07/66	Spring	Bedrock	Weathered	210	7.8	26	4.8	7.2

Appendix IID. Bedrock Aquifer Baseline Water Quality Data.

IID-6

Well #	Date	mg/l					ug/l			
		K Potassium	Cl Chloride	HCO ₃ Bicarbonate	CO ₃ Carbonate	CaCO ₃ Tot Alk	Al Aluminum	Sb Antimony	As Arsenic	Be Beryllium
Well D-2	05/29/92	15.4	11.4	33.9	0		200		38	
	May 1991	15.6	NA			31	121		17.7	
	5/31/91	16.4	5.8	31.8	0.0		<80		10.0	NA
	Aug 1991	15.6	NA			24	70.8		7.9	
	8/31/94	29.7	17.5	46.3	6.7		<30		3.4	<2
Well E	05/29/92	12.7	5.8	41.4	0		<100		32	
	05/29/92	13	5.8	41.6	0		150		32	
	May 1991	10.9	NA			30	29		32.5	
	8/25/94	14.1	5	39.5	0.0		<30		27.0	<2
	Sept 1991	11.2	NA			42	184		38.4	
Well F	7/31/92	24.0	21.7	160.0	0.0		<20		242.0	NA
	4/19/93	23.6	22.1	202.0	0.0		<30		240.0	<2
	5/19/93	22.3	18	127.0	20		52		254.0	
	5/19/93	20	16	129	20		46.9		232	
	8/24/94	23.1	17.5	77.2	0.0		<30		273.8	<2
93-69	07/19/90	3.79	13.2	185	0		74		2.7	0.025
93-70	?	3	13.1	167	0		30		4.5	
93-73	11/16/89	3.46	14.4	229	0		40		1.3	0.047
	?	3.7	18.3	262	0		30		2.7	
93-83	11/01/88	5.6	42.1	258	0		30		7.36	0.055
25 CAD	09/04/68	NA	5.7	132	0					
36 ADA	09/04/68	NA	5.4	113	0					
31 CCB	08/26/66	3.3	4.2	89	0					
06 BBB	08/26/66	3.4	6.3	96	0					
06 CBD	08/24/66	3.5	6.9	59	0					
27 CAD	07/07/66	NA	2.4	80	0					

Appendix IID. Bedrock Aquifer Baseline Water Quality Data.

IID-8

Well #	Date	mg/l	ug/l				Reference
		SO4 Sulfate	Tl Thallium	V Vanadium	Zn Zinc	Zr Zirconium	
Well D-2	05/29/92	654		78	1691	77	5
	May 1991	598			1690		6
	5/31/91	95.2			1580		5
	Aug 1991	647			1900		6
	8/31/94	83.2			2		5
Well E	05/29/92	357		56	23	29	5
	05/29/92	353		58	19	44	5
	May 1991	390			27		6
	8/25/94	90.2			16		5
	Sept 1991	404			72.3		6
Well F	7/31/92	83.3			47		5
	4/19/93	78.9			125		5
	5/19/93	720			126		6
	5/19/93	720			115		6
	8/24/94	89.9			101		5
93-69	07/19/90	392			18		8
93-70	?	147			70		8
93-73	11/16/89	226			172		8
93-83	?	101			10		8
	11/01/88	514			545		8
25 CAD	09/04/68	40					3
36 ADA	09/04/68	40					3
31 CCB	08/26/66	70					3
06 BBB	08/26/66	53					3
06 CBD	08/24/66	65					3
27 CAD	07/07/66	22					3

6-9

[illegible]

Appendix IID. Bedrock Aquifer Baseline Water Quality Data.

[illegible]

Appendix IID. Bedrock Aquifer Baseline Water Quality Data.

IID-12

Well #	Date	mg/l	ug/l				Reference
		SO ₄ Sulfate	Thallium Tl	Vanadium V	Zinc Zn	Zirconium Zr	
Spring 1	02/03/09	52					4
Spring 2	11/18/13	8.9					4
Well	02/26/10	5.1					4
MCL							
SMCL		250			5000		
Mean* (n)							

References:

- 1 = CH2M HILL/Chen-Northern, 1990, Vol. II, Appendix B-3 and B-4;
limited data for well BMW-5 from isopleth maps.
- 2 = MultiTech, 1987, Appendix B, Part 4, Attachment VI-A.
- 3 = Botz, 1969, Table 7.
- 4 = Meinzer, 1914, pg. 97.
- 5 = MBMG, 1992 and 1994, Bedrock sampling.
- 6 = Canonie, 1992a, Table 6.3.1.; Canonie, 1994, Tables 6.3.6 and 6.3.7
- 7 = MultiTech/MSE, 1992. Bedrock Monitoring Task Second Quarterly Sampling Report, Feb. 1992.
- 8 = Canonie, 1994, Table 8.3.1 and 8.4.2.

APPENDIX III

ALLUVIAL GROUNDWATER QUALITY DATA

- A - Area I Data***
- B - Leach Pads Area Data**
- C - Leach Pads Area Historic Data**
- D - Alluvial Aquifer Baseline Water Quality Data**

* includes some wells completed in bedrock.

Appendix IIIA. Area I Alluvial Groundwater Quality Data

IIIA-1

Well #	Water Qual Sampling Date	Depth (ft.) Screened Interval	Average Screened Depth	Probable Aquifer	Static Water Level	Date	Measuring Point Elevation (ft.)	MP Height from G.S. (ft.)
AI-GW-GS-07	08/24/89	130-160	145	Ts/Qal	25.6	11/27/85	5479.90	2.2
	11/06/89				24.3	10/89	5479.40	1.9
	04/17/90							
AI-GW-GS-08	08/24/89	125.5-145.5	135.5	Ts/Qal	12.4	11/26/85	5458.00	1.5
	11/07/89				9.9	10/89	5458.00	1.5
	11/07/89				10.8	10/89	5457.40	1.1
	04/18/90							
AI-GW-GS-12	08/25/89	19.5-29.5	24.5	Qal	11.0	12/03/85	5442.70	1.5
	11/13/89				8.8	10/89	5442.70	1.5
AI-GW-GS-13A	08/25/89	12.5-17.5	15	Qal	6.2	12/18/85	5441.20	1.6
					5.1	08/89	5441.20	1.6
AI-GW-GS-13B	11/13/89	24-28, 31-32	26, 31.5	Qal	5.8	12/19/85	5440.60	0.5
					5.0	09/89	5440.60	0.5
AI-GW-GS-14	08/25/89	52-62	57	Ts/Qal	9.3	12/20/85	5455.20	1.6
	11/09/89				8.1	10/89	5455.20	1.6
	04/19/90							
AI-GW-GS-15D (15A)	08/25/89	27-32	29.5	Qal	9.5	10/89	5445.30	0.9
	11/09/89				9.0	12/17/85	5445.30	0.9
	04/23/90							
	04/23/90							
AI-GW-GS-15S (15B)	08/25/89	0-15	7.5	Qal	9.8	10/89	5445.30	0.9
	11/09/89				9.2	12/17/85	5445.30	0.9
	04/23/90							
	04/23/90							
AI-GW-GS-16	08/25/89	11.2-16.2	13.7	Qal	9.0	10/89	5440.40	2.0
	11/13/89							
	04/23/90							
AI-GW-GS-17D	08/22/89	17.7-27.7	22.7	Qal	3.2	10/89	5434.10	2.1
	08/22/89							
	11/13/89							
	04/19/90							

Appendix IIIA. Area I Alluvial Groundwater Quality Data

IIIA-2

Well #	Water Qual Sampling		(umhos/cm)		(mV)		(ug/l)				(mg/l)	
	Date	pH	SC	Eh	Al	As	Be	Cd	Ca			
AI-GW-GS-07	08/24/89	5.5	3021		72.8S	<0.6S	2.5	135	468			
	11/06/89	5.5	2693	255	320	<3.0	<1.0	93.0	470S			
	04/17/90	5.6	3130		126S	1.8S	<1.0	100S	372S			
AI-GW-GS-08	08/24/89	6.6	1211	-300	<11.5S	3.7S	2.5	7.0S	176			
	11/07/89	6.2	2429	265	82S	<3.0	<1.0	360	140S			
	11/07/89	6.4	1212	190	100S	4.8	<1.0	260	360S			
	04/18/90	5.9	2234		95.2S	<0.7	<1.0	169	289			
AI-GW-GS-12	08/25/89	7.1	578	60	11.6S	4.2S	1.7	18.3	74.1			
	11/13/89	6.7	451	180	270S	4.0S	<1.0	12.0S	62.0			
AI-GW-GS-13A	08/25/89	6.6	1313	-70	15.6S	4.8S	<1.0	42.0	233			
AI-GW-GS-13B	11/13/89	6.6	1575	150	180S	<3.0S	<1.0	1.5S	140			
AI-GW-GS-14	08/25/89	6.5	1700	80	<11.5	33.4S	5.0	10.8	243			
	11/09/89				260S	7.9S	<1.0	4.5	270			
	04/19/90	6.4	1931		<22.0	2.7S	<1.0	6.4S	284			
AI-GW-GS-15D (15A)	08/25/89	7.4	405	50	<11.5	11.6S	1.7	5.3S	52.0			
	11/09/89	7.1	549	90	75.0S	9.5	<1.0	4.2S	43.0			
	04/23/90	7.2	495		<22.0	6.4S	<1.0	4.8R	51.1S			
	04/23/90				<22.0	6.9S	<1.0	4.5R	50.7S			
AI-GW-GS-15S (15B)	08/25/89	6.3	473	120	<11.5	5.7S	1.7	6.9	56.8			
	11/09/89	7.0	508	90	200S	13.0	<1.0	8.3	48.0			
	04/23/90	6.9	512		<22.0	12.1S	<1.0	4.5R	57.9S			
AI-GW-GS-16	08/25/89	6.6	769	-80	14.0S	1.8S	<1.0	364	82.4			
	11/13/89	5.8	905	190	230S	<3.0S	<1.0	430	64.0			
	04/23/90	6.6	837		<22.0	1.9S	<1.0	333S	80.7S			
AI-GW-GS-17D	08/22/89	6.7	752	140	<11.5	4.6	<1.0	9.8S	84.2			
	08/22/89				<11.5	2.0	<1.0	5.1S	78.0			
	11/13/89	6.7	819	141	120S	5.5S	<1.0	1.6S	75.0			
	04/19/90	6.7	1000		<22.0	4.4S	<1.0	6.2S	103			

Well #	Water Qual Sampling									
	Date	Cr	Co	Cu	Fe	Pb	Mg	Mn	Ni	
AI-GW-GS-07	08/24/89	<2.8S	20.9	4960S	1490S	<5.0S	136	30900	151	
	11/06/89	21.0S	30.0	5900	560S	<0.4S	130	27000S	100	
	04/17/90	<8.0	27.3S	4440S	1750S	1.6S	125S	25700S	125S	
AI-GW-GS-08	08/24/89	<2.8S	<2.6	25.0S	17S	<0.5S	28.9	62	8.6	
	11/07/89	<8.0S	<12.0	35.0S	15S	300S	29.0	60S	2.0	
	11/07/89	22.0S	31.0	10000	2000S	230	110	34000S	28.0	
	04/18/90	<8.0	37.5	6090	3580	194S	88.2	32900	26.2S	
AI-GW-GS-12	08/25/89	<2.8	<2.6	<1.1S	<4	<0.5	18.0	2230S	<1.1S	
	11/13/89	14.0	14.0	<6.0	57S	0.4R	16.0S	1600S	4.5S	
AI-GW-GS-13A	08/25/89	<2.8S	<2.6	529S	153S	61.5S	36.0	61500	28.9	
AI-GW-GS-13B	11/13/89	<8.0	22.0	<6.0	2700	0.4R	38.0S	7800S	<2.0S	
AI-GW-GS-14	08/25/89	<2.8	5.3	16.4S	880	<5.0S	59.8	532S	<1.1S	
	11/09/89	<8.0	24.0	<6.0S	110S	<0.4S	65.0S	130	<2.0	
	04/19/90	<8.0	<8.0	8.4	<5	<0.5S	74.8	48	1.6S	
AI-GW-GS-15D (15A)	08/25/89	<2.8	<2.6	37.8S	8.0	<0.5	12.3	149S	<1.1S	
	11/09/89	<8.0	19.0	45.0S	26S	<0.4S	12.0S	140	<2.0	
	04/23/90	<8.0	<8.0	51.7	<5S	0.5	11.8	135S	<1.3S	
	04/23/90	<8.0	<8.0	48.2	<5S	<0.5	11.7	135S	<1.3S	
AI-GW-GS-15S (15B)	08/25/89	<2.8	<2.6	218S	9.0	2.6	12.8	20S	<1.1S	
	11/09/89	<8.0	22.0	170S	48S	<0.4S	12.0S	26S	<2.0	
	04/23/90	<8.0	<8.0	184	<5S	3.1	12.5	6S	<1.3S	
AI-GW-GS-16	08/25/89	<2.8S	3.3	49.7S	6S	12.2S	26.5	11000	15.1	
	11/13/89	16.0	<12.0	43.0	250S	2.2S	31.0S	13000S	25.0S	
	04/23/90	<8.0	<8.0	37.2	<5S	18.5	27.0	10400S	13.1R	
AI-GW-GS-17D	08/22/89	<2.8S	8.4	40.8	<4	0.7S	18.7	1230	3.4S	
	08/22/89	<2.8S	7.0	35.7	<4	<0.5S	16.7	1120	2.5S	
	11/13/89	<8.0	23.0	13.0	49S	0.4R	20.0S	310S	<2.0S	
	04/19/90	<8.0	<8.0	32.1	<5	1.0	25.1	648	<1.3S	

Appendix IIIA. Area I Alluvial Groundwater Quality Data

IIIA-4

Well #	Water Qual Sampling Date	(mg/l)			(ug/l)			(mg/l)					Total Alk (mg/l)
		K	Na		Tl	Zn		Cl	F	Nitrate + Nitrite N	Sulfate		
AI-GW-GS-07	08/24/89	33.6S	181		2.0R	29800		29.8	<0.05	<0.05	2414		13
	11/06/89	36.0S	190		370	31000		22.4	<0.10	<0.01S	2470		107
	04/17/90	30.2	167S		<2.0S	24500S		27.0	0.56	0.05S	1980		13
AI-GW-GS-08	08/24/89	15.5S	97.9		20.0S	822		11.8	0.79	3.09	230		64
	11/07/89	16.0S	110		<9.0	720		33.6	<0.10	<0.01S	1480		148
	11/07/89	36.0S	130		610	72000		48.5	0.55	<0.01S	562		92
	04/18/90	22.3	98.2		<2.0	30300		30.0	0.58	0.05S	1280S		100
AI-GW-GS-12	08/25/89	8.72S	31.6		20.0R	1300		39.1	1.31	2.60	163		100
	11/13/89	8.10	29.0		24.0	1200		25.6	1.10	2.40	486		111
AI-GW-GS-13A	08/25/89	12.0S	18.6		20.0S	16600		25.6	3.07	0.28	706		158
AI-GW-GS-13B	11/13/89	8.80	30.0		110	360		21.9	0.96	3.60	721		197
AI-GW-GS-14	08/25/89	13.9	87.0		20.0R	591		34.4	<0.05	1.62	3550		<2
	11/09/89	12.0	86.0		<9.0	420S		29.0	<0.10	0.99S	1410		75S
	04/19/90	16.0	111		<2.0S	491S		32.0	0.40	1.20S	980		48
AI-GW-GS-15D (15A)	08/25/89	4.12S	29.6		20.0R	345		37.0	0.97	4.50	60.8		105
	11/09/89	4.40	28.0		<9.0	310S		27.4	0.84	4.60	48.8		136
	04/23/90	4.21	30.1		<2.0S	312S		40.0S	1.10S	4.00S	51.0S		110
	04/23/90	4.34	29.8		<2.0S	311S		38.0S	1.20S	3.90S	49.0S		110
AI-GW-GS-15S (15B)	08/25/89	4.20S	29.4		20.0R	525S		38.0	0.94	4.74	67.5		110
	11/09/89	4.30	26.0		<9.0	510S		27.9	0.76	4.94	55.4		148
	04/23/90	4.50	30.4		<2.0S	531S		38.0S	1.10S	3.40S	61.0S		120
AI-GW-GS-16	08/25/89	8.98S	32.2		20.0S	52000		40.9	5.16	2.85	280		118
	11/13/89	7.30	26.0		160	66000		30.6	3.50	2.90	345		126
	04/23/90	8.82	34.8		<2.0S	56100S		33.0S	1.20S	2.30S	250S		120
AI-GW-GS-17D	08/22/89	6.44	59.6		20.0R	1220		41.6	0.89	3.99	22.2		102
	08/22/89	5.85	52.3		20.0R	1080		41.6	0.89	3.93	22.2		103
	11/13/89	6.60	78.0		<9.0	390		39.1	0.61	5.80	272		126
	04/19/90	7.03	68.9		<2.0	881S		50.0	0.73	7.60	190		140

Appendix IIIA. Area I Alluvial Groundwater Quality Data

IIIA-5

Well #	Water Qual Sampling Date	Depth (ft.) Screened Interval	Average Screened Depth	Probable Aquifer	Static Water Level	Date	Measuring Point Elevation (ft.)	MP Height from G.S. (ft.)
AI-GW-GS-17S	08/22/89 11/13/89 04/19/90	3-8	5.5	Qal	3.8	10/89	5434.70	2.8
AI-GW-GS-18	08/25/89 11/13/89 04/19/90	11-16	13.5	Qal	10.0	10/89	5439.10	2.2
AI-GW-GS-19	08/24/89 11/13/89	13.5-18.5	16	Qal	13.2	10/89	5445.30	1.6
AI-GW-GS-20	08/24/89 11/10/89 04/20/90	18-23	20.5	Qal	18.6	10/89	5457.20	1.9
AI-GW-GS-21D	08/25/89 08/25/89 11/09/89 04/23/90	23.6-33.6	28.6	Qal	13.2	10/89	5447.80	1.8
AI-GW-GS-21S	08/25/89 11/09/89 04/23/90	11-21	16	Qal	13.0	10/89	5447.60	1.6
AI-GW-GS-22	08/25/89 11/13/89 04/24/90	5-15	10	Qal	7.6	10/89	5435.90	2.5
AI-GW-GS-23	08/24/89 11/14/89	14.5-19.5	17	Qal	14.9	10/89	5437.20	1.5
AI-GW-GS-24D	08/22/89 11/14/89 11/14/89 04/23/90	21.7-31.7	26.7	Qal	6.8	10/89	5433.50	1.6
AI-GW-GS-24S	08/22/89 11/14/89 04/23/90	9.5-14.5	12	Qal	7.3	10/89	5434.10	1.8

Appendix IIIA. Area I Alluvial Groundwater Quality Data

IIIA-6

Well #	Water Qual										(mg/l) Ca
	Sampling Date	pH	(umhos/cm)		(mV) Eh	(ug/l)					
			SC			Al	As	Be	Cd		
AI-GW-GS-17S	08/22/89	4.6	1648		250	13500	2.7	8.1	937	134	
	11/13/89	4.3	1341		230	9300S	3.9S	4.7	620	73.0	
	04/19/90	5.3	799			1490	1.5S	1.0	218	41.8	
AI-GW-GS-18	08/25/89	6.8	1272		20	<11.5	2.8S	<1.0	68.2	177	
	11/13/89	6.2	961		200	100S	3.2S	<1.0	35.0	93.0	
	04/19/90	6.7	1074			<22.0	3.2S	<1.0	23.8	143	
AI-GW-GS-19	08/24/89	6.4	704		100	<11.5	13.2S	1.7	60.3	78.9	
	11/13/89	6.3	675		175	92.0S	11.0S	<1.0	50.0	54.0	
AI-GW-GS-20	08/24/89	6.6	464		80	<11.5	1.7S	2.5	3.5S	71.2	
	11/10/89	7.1	564		140	170S	<3.0S	<1.0	5.2	67.0	
	04/20/90	6.7	617			<22.0	1.9S	<1.0	2.9S	66.4	
AI-GW-GS-21D	08/25/89	7.2	756		-30	<11.5	6.6S	<1.0	5.6S	94.1	
	08/25/89					<11.5	6.6S	<1.0	5.3S	92.2	
	11/09/89	7.1	686		90	170S	11.0	<1.0	3.5S	74.0	
	04/23/90	7.1	774			<22.0	9.6S	<1.0	6.2R	99.3S	
AI-GW-GS-21S	08/25/89	7.0	665		30	15.0	19.1S	<1.0	9.5	92.7	
	11/09/89	7.0	721		110	210S	23.0	<1.0	6.4	71.0	
	04/23/90	7.0	731			<22.0	22.5S	<1.0	9.0R	97.5S	
AI-GW-GS-22	08/25/89	7.4	1126		-330	<11.5	158S	1.7	2.4S	152	
	11/13/89	6.5	1024		160	300S	110S	<1.0	3.7S	100	
	04/24/90	7.6	1004			<22.0	63.0S	<1.0	1.1R	126S	
AI-GW-GS-23	08/24/89	7.3	704		-390	<11.5	11.7S	1.7	0.6S	110	
	11/14/89	6.8	702		190	280S	12.0S	<1.0	0.5S	76.0	
AI-GW-GS-24D	08/22/89	6.5	955		-20	<11.5	1.4	<1.0	17.9	73.3	
	11/14/89	6.0	807		150	180S	<3.0S	<1.0	30.0	56.0	
	11/14/89	6.1	807		155	230S	<3.0S	<1.0	28.0	51.0	
	04/23/90	6.7	963			<22.0	1.4S	<1.0	30.0S	66.2S	
AI-GW-GS-24S	08/22/89	6.5	2040		40	28.5	802	1.6	13.2	200	
	11/14/89	6.4	1847		90	130S	1210S	<1.0	4.3S	240	
	04/23/90	6.5	2492			<22.0	1440S	<1.0	7.5R	190S	

Well #	Water Qual									
	Sampling Date	(ug/l)			(mg/l)			(ug/l)		
		Cr	Co	Cu	Fe	Pb	Mg	Mn	Ni	
AI-GW-GS-17S	08/22/89	<2.8S	64.2	79400	320	3520	39.2	98700	51.8	
	11/13/89	43.0	37.0	62000	220S	2600S	28.0S	79000S	33.0S	
	04/19/90	<8.0	16.0	23500	8.0	2920	13.9	27600	12.0S	
AI-GW-GS-18	08/25/89	<2.8S	4.9	1220S	12S	0.8S	28.6	7860	9.9	
	11/13/89	<8.0	30.0	790	82S	0.4R	30.0S	3900S	4.2S	
	04/19/90	<8.0	<8.0	555	<5	<0.5	30.7	3610	5.3S	
AI-GW-GS-19	08/24/89	<2.8S	<2.6	748S	26S	89.8S	14.7	4220	7.6	
	11/13/89	11.0	<12.0	720	52S	110S	17.0S	4300S	7.1S	
AI-GW-GS-20	08/24/89	<2.8S	<2.6	<1.1S	42S	<0.5S	14.6	25S	<1.1S	
	11/10/89	<8.0	20.0	<6.0S	<12S	<0.4S	21.0S	30S	<2.0	
	04/20/90	<8.0	<8.0	5.9	<5	1.0	16.7	4S	1.6S	
AI-GW-GS-21D	08/25/89	<2.8S	<2.6	72.5S	10S	5.3S	22.6	137	1.7	
	08/25/89	<2.8S	<2.6	57.0S	11S	2.6S	22.2	146	3.2	
	11/09/89	<8.0	34.0	75.0S	16S	<0.4S	20.0S	34S	<2.0	
	04/23/90	<8.0	<8.0	126	<5S	<0.5S	23.0	31S	1.4S	
AI-GW-GS-21S	08/25/89	<2.8	<2.6	562.0S	16S	16.2	22.7	2130	8.2	
	11/09/89	<8.0	14.0	390.0S	<12S	61.0	21.0S	2400	3.4	
	04/23/90	<8.0	8.1	1080	<5S	14.6	23.1	2650S	1.8S	
AI-GW-GS-22	08/25/89	<2.8	<2.6	10.0S	<4	<0.5S	36.1	42S	8.9S	
	11/13/89	22.0	24.0	20.0	160S	0.4R	28.0S	40S	10.0S	
	04/24/90	<8.0	<8.0	22.7S	<5S	<0.5S	32.8	5S	1.6R	
AI-GW-GS-23	08/24/89	<2.8S	2.7	<1.1S	<4S	<0.5S	20.3	9S	<1.1	
	11/14/89	20.0	<12.0	<6.0	130S	0.4R	20.0S	14S	12.0S	
AI-GW-GS-24D	08/22/89	<2.8S	3.3	16.0S	264	1.3S	17.8	12800	4.3S	
	11/14/89	<8.0	17.0	<6.0	71S	0.4R	16.0S	15000S	4.7S	
	11/14/89	13.0	<12.0	<6.0	33S	0.4R	15.0S	13000S	4.3S	
	04/23/90	<8.0	<8.0	19.1S	<5S	4.2	15.2	13100S	11.0R	
AI-GW-GS-24S	08/22/89	<2.8S	7.7	18.2	4060	48.1	40.3	105000	4.2S	
	11/14/89	67.0	<12.0	<6.0	8700	83.0S	43.0S	100000S	9.4S	
	04/23/90	<8.0	16.0	10.9	8100	54.7	37.2	108000S	3.7R	

Appendix IIIA. Area I Alluvial Groundwater Quality Data

IIIA-8

Well #	Water Qual			(mg/l)			(ug/l)			(mg/l)				(mg/l)
	Sampling Date	K	Na	TI	Zn	Cl	F	N	Sulfate	Nitrate + Nitrite				Total Alk
AI-GW-GS-17S	08/22/89	7.79	32.8	2.0R	22000	33.6	4.09	1.45	1592					<2S
	11/13/89	7.00	29.0	960	190000	22.9	1.10	2.00	910					<3S
	04/19/90	6.19	29.8	<2.0S	67500S	37.0	1.00	1.20S	290					5
AI-GW-GS-18	08/25/89	4.27S	38.7	20.0S	32800	25.8	0.88	2.28	541					162
	11/13/89	3.90	32.0	46.0	15000	18.6	<0.10	1.80	413					177
	04/19/90	6.33	52.4	<2.0	8620S	23.0	0.52	1.70S	330					180
AI-GW-GS-19	08/24/89	8.21S	22.5	20.0S	14700	30.5	1.98	2.15	228					76
	11/13/89	7.10	21.0	68.0	13000	21.4	1.60	1.80	234					93
AI-GW-GS-20	08/24/89	5.883S	23.4	20.0S	711	26.9	1.14	2.84	149					101
	11/10/89	6.80	27.0	<9.0	710S	29.9	0.70	6.56	220					133
	04/20/90	6.12	32.6	<2.0	643S	50.0	0.82	2.40S	160					100
AI-GW-GS-21D	08/25/89	4.92S	39.5	20.0S	502	60.6	0.87	8.92	127					141
	08/25/89	5.35S	40.3	20.0S	460	60.9	0.79	8.92	127					141
	11/09/89	5.50	36.0	<9.0	260S	48.5	0.48	9.87	115					165
AI-GW-GS-21S	04/23/90	5.59	40.1	<2.0S	428S	66.0S	.68S	9.10S	160S					160
	08/25/89	4.88S	38.2	20.0S	1190	67.6	1.09	3.21	149					149
	11/09/89	4.40	33.0	26.0	630S	53.5	0.80	2.71	146					196
AI-GW-GS-22	04/23/90	6.39	39.0	<2.0S	1590S	64.0S	.99S	3.40S	130S					160
	08/25/89	14.9S	86.1	20.0R	71	18.6	1.70	1.94	422					221
	11/13/89	13.0	66.0	23.0	320	12.6	2.00	1.90	359					303
AI-GW-GS-23	04/24/90	14.0	76.4	<2.0S	154S	32.0S	1.20S	1.90S	490S					260
	08/24/89	2.62S	47.5	20.0S	30S	11.7	0.80	3.12	231					182
	11/14/89	3.60	48.0	<9.0	17S	6.9	0.56	3.30	220					197
AI-GW-GS-24D	08/22/89	11.6	107	20.0R	4340	43.8	1.35	1.82	324					93
	11/14/89	9.30	67.0	220	12000	32.8	1.14	1.66S	358					114
	11/14/89	7.70	63.0	180	12000	32.2	1.12	1.89S	348					102
	04/23/90	10.1	84.1	<2.0S	11100S	46.0S	1.50S	1.90S	300S					80
AI-GW-GS-24S	08/22/89	19.2	229	20.0R	13200	51.8	3.04	0.16	1280					159
	11/14/89	21.0	310	1400	11000	41.3	1.20	<0.01	1260					222
	04/23/90	19.3	239	2.1S	15000S	57.0S	1.40S	0.29S	960S					160

[illegible]

Appendix IIIA. Area I Alluvial Groundwater Quality Data

IIIA-10

Well #	Water Qual												
	Sampling Date	pH	(umhos/cm)		(mV)	(ug/l)			(mg/l)				
			SC	Eh		Al	As	Be	Cd		Ca		
AI-GW-GS-25	08/24/89	6.6	1100	-300		82.0	42.2S	5.0	60.2		152		
	11/14/89	6.2	919	190		210S	40.0S	<1.0	53.0		100		
	04/24/90	6.7	1104			52.7	25.5S	<1.0	71.0S		150S		
AI-GW-GS-26	08/22/89	4.7	1962	200		3090	43.4	3.3	276		199		
	11/14/89	5.0	1623	230		2700S	5.6S	2.7	240		160		
	04/25/90	6.0	1840			6070	216	5.5	405S		265		
AI-GW-GS-27D	08/22/89	6.3	2953	-20		<11.5	223	1.6	0.7S		253		
	11/15/89	6.1	2726	-30		300S	190S	<1.0	1.2S		240		
	04/24/90	6.6	1863			28.6	132S	<1.0	<0.03S		244S		
AI-GW-GS-27S	08/22/89	6.4	2953	-30		<11.5	146	<1.0	0.3S		199		
	11/15/89	6.8	2792	-25		220S	180S	<1.0	1.3S		200		
	04/24/90	7.0	1830			34.0	369S	<1.0	0.11S		212S		
AI-GW-GS-28	08/23/89	5.9	1312	-300		74.6	5.4S	3.4	0.8S		152		
	11/09/89	6.6	1174	150		73.0S	7.9	<1.0	1.0S		110		
	08/23/89	7.1	1212	-320		<11.5	17.4S	1.7	2.4S		114		
AI-GW-GS-29D	11/09/89	7.2	849	145		180S	19.0	<1.0	1.1S		69.0		
	04/23/90	7.0	1114			<22.0	30.0S	<1.0	0.44R		119S		
	08/23/89	6.6	1388	-180		<11.5	19.5S	<1.0	0.7S		199		
AI-GW-GS-29S	11/09/89	6.6	1474	150		<41.0S	38.0	<1.0	1.3S		140		
	04/23/90	6.7	1507			<22.0	72.5S	<1.0	0.90R		221S		
	08/18/89	6.3	3438	40		<11.5	2.4S	2.4	27.1		622		
AI-GW-GS-30D	11/07/89	6.7	3390			230S	<3.0	<1.0	17.0		600S		
	11/07/89	6.5	3374			<41.0S	<3.0	<1.0	17.0		520S		
	04/18/90	6.2	3189			26.3S	1.2	<1.0	21.6		515		
AI-GW-GS-30S	08/18/89	6.4	1965	30		451	27.1	3.1	0.9S		216		
	11/07/89	6.1	1416	120		110S	13.0	<1.0	1.1S		230S		
	04/18/90	6.3	1142			58.9S	13.0	<1.0	0.09S		184		
AI-GW-GS-31D	08/23/89	6.0	1267	190		<11.5	<0.6S	<1.0	3.6S		188		
	11/08/89	5.7	1454	150		110S	<3.0	<1.0	0.9S		170S		
	04/19/90	6.4	1437			<22.0S	1.4S	<1.0	1.9S		212		

Appendix IIIA. Area I Alluvial Groundwater Quality Data

IIIA-11

Well #	Water Qual									
	Sampling Date	Cr	Co	Cu	Fe	Pb	(mg/l)		(ug/l)	
							Mg		Mn	Ni
AI-GW-GS-25	08/24/89	<2.8S	<2.6	140.0S	110S	<0.5S	25.4		14800	7.9
	11/14/89	12.0	18.0	61.0	98S	0.4R	23.0S		7900S	9.2S
	04/24/90	<8.0	12.4	161	<5S	<0.5	25.6		13800S	5.9S
AI-GW-GS-26	08/22/89	<2.8S	91.9	17800	869000	259S	41.0		35600	81.6
	11/14/89	15.0	74.0	19000	72000	160S	40.0S		30000S	41.0S
	04/25/90	<8.0	162	29900	136000S	291	57.0		45300	108
AI-GW-GS-27D	08/22/89	<2.8S	8.2	10.2S	132000	<0.5S	66.7		34500	6.7S
	11/15/89	<8.0	17.0	<6.0S	120000	<0.4S	53.0S		32000	<2.0
	04/24/90	<8.0	<8.0	<4.0S	135000	<0.5S	62.5		34700S	8.5R
AI-GW-GS-27S	08/22/89	<2.8S	6.2	4.4S	87900	<5.0S	56.5		27400	1.6S
	11/15/89	<8.0	15.0	<6.0S	90000	<0.4S	56.0S		28000	3.0
	04/24/90	<8.0	13.4	5.5S	98200	<0.5S	58.9		29200S	1.3S
AI-GW-GS-28	08/23/89	<2.8S	12.0	10.7S	1450S	<0.5S	387		559	2.1
	11/09/89	<8.0	19.0	<6.0S	710	<0.4S	35.0		500S	<2.0
AI-GW-GS-29D	08/23/89	<2.8S	<2.6	1.4S	<4S	<0.5S	29.4		71	<11.0S
	11/09/89	<8.0	15.0	<6.0S	<12S	<0.4S	27.0S		12S	<2.0
	04/23/90	<8.0	<8.0	<4.0	<5S	<0.5S	30.4		<2S	<1.3S
AI-GW-GS-29S	08/23/89	<2.8S	<2.6	2.9S	22S	<5.0S	52.3		1700	8.3
	11/09/89	<8.0	<12.0	<6.0S	2600	<0.4S	46.0S		1300	4.5
	04/23/90	<8.0	<8.0	<4.0	3280	0.7S	56.4		1860S	6.0R
AI-GW-GS-30D	08/18/89	16.0	28.2	135	3480	<0.5S	167		15200	87.0
	11/07/89	<8.0S	25.0	59.0S	3500S	<0.4S	140		8000S	25.0
	11/07/89	13.0S	31.0	130	2800S	<0.4S	140		8500S	24.0
AI-GW-GS-30S	04/18/90	16.5	15.5	469	239	<2.5S	143		4240	39.0
	08/18/89	<2.8	<2.6	8.9	14700	20.6	60.4		21200	5.9S
	11/07/89	17.0S	23.0	29.0S	14000S	<0.4S	63.0		26000S	5.9
AI-GW-GS-31D	04/18/90	<8.0	<8.0	<4.0	19500	<2.5S	57.1		24200	1.5
	08/23/89	<2.8S	7.0	21.8	24.0	<5.0S	49.9		86	1.5S
	11/08/89	8.0S	27.0	52.0S	53.0	<0.4S	53.0S		140S	3.0
	04/19/90	<8.0	<8.0	<4.0	<5	<2.5	65.2		6	1.4S

Appendix IIIA. Area I Alluvial Groundwater Quality Data

IIIA-12

Well #	Water Qual Sampling Date	(mg/l)			(ug/l)			(mg/l)					(mg/l)
		K	Na		'11	Zn		Cl	F	Nitrate + Nitrite N	Sulfate	Total Alk	
AI-GW-GS-25	08/24/89	9.92S	51.8		20.0S	24000		37.4	5.04	0.49	480	109	
	11/14/89	7.60	43.0		210	25000		25.5	2.90	0.46	380	101	
	04/24/90	9.32	53.6		<2.0S	26800S		37.0S	4.60S	0.25S	500S	120	
AI-GW-GS-26	08/22/89	8.79	78.7		2.0R	82900		55.0	3.30	0.17	1300	<2S	
	11/14/89	7.80	77.0		350	77000		41.4	1.00	<0.01	1100	<3S	
	04/25/90	8.73	110		<2.0S	132000S		55.0S	0.92S	<0.01S	1780S	<5	
AI-GW-GS-27D	08/22/89	13.6	294S		20.0R	1200		671	3.96	<0.05	515	146	
	11/15/89	18.0	300S		380	1500		626	1.53	<0.01S	517	267	
	04/24/90	13.5	315		<2.0S	1320S		640S	2.50S	<0.01S	590S	220	
AI-GW-GS-27S	08/22/89	20.9	306		20.0R	2650		684	4.99	<0.05	536	154	
	11/15/89	25.0	350S		260	1800		651	3.68	<0.01S	542	274	
	04/24/90	23.8	357		<2.0S	2730S		640S	2.80S	<0.01S	590S	220	
AI-GW-GS-28	08/23/89	8.55S	55.9		20.0S	267		28.0	1.29	0.16	562	69	
	11/09/89	7.70	43.0		13.0	160S		20.3	<0.10	0.02S	448	92S	
AI-GW-GS-29D	08/23/89	10.2S	103		20.0S	53S		12.2	2.00	<0.05	508	92	
	11/09/89	6.90	67.0		22.0	7S		11.1	1.35	<0.01S	385	124S	
	04/23/90	11.3	109		<2.0S	16S		20.0S	1.80S	0.12S	580S	220	
AI-GW-GS-29S	08/23/89	11.7S	87.2		20.0S	1400		24.8	1.69	1.72	756	89	
	11/09/89	11.0	66.0		23.0	900S		19.8	0.71	0.82S	619	114S	
	04/23/90	15.4	94.6		<2.0S	2250S		31.0S	0.82S	<0.01S	500S	110	
AI-GW-GS-30D	08/18/89	24.3	110		20.0R	2900		42.2	2.20	0.61	1320	76	
	11/07/89	20.0S	100		140	3000		27.6	<0.10	<0.50S	2560	73	
	11/07/89	18.0S	94.0		120	3000		31.4	<0.10	0.65S	2340	68	
AI-GW-GS-30S	04/18/90	18.0	86.7		<2.0	3650		57.0	0.55	1.40S	2620S	73	
	08/18/89	12.0	596		20.0R	161		42.2	1.59	<0.05	887	139	
	11/07/89	8.30S	56.0		410	83S		39.7	<0.10	<0.01S	753	126	
AI-GW-GS-31D	04/18/90	8.96	50.3		<2.0	73		40.0	0.27	<0.01S	970S	100	
	08/23/89	9.48	48.7		20.0R	341		21.7	0.84	3.93	757	58	
	11/08/89	11.0	57.0S		<9.0	330		11.9	<0.10	1.92	770S	83S	
	04/19/90	13.9	72.6		<2.0	173S		18.0	0.34	2.20S	610S	65	

Well #	Water Qual Sampling Date	Depth (ft.) Screened Interval	Average Screened Depth	Probable Aquifer	Static Water Level	Date	Measuring Point Elevation (ft.)	MP Height from G.S. (ft.)
AI-GW-GS-31S	08/23/89 11/08/89 04/19/90	14.6-19.6	17.1	Qal	5.1	10/89	5451.60	1.1
AI-GW-GS-32	08/23/89 11/08/89 04/18/90	27-37	32	Qal	3.5	10/89	5450.80	2.1
AI-GW-GS-33	08/17/89 11/08/89 04/20/90	39-49	44	Qal	25.4	10/89	5474.90	1.8
AI-GW-GS-34D	08/22/89 11/14/89 04/24/90	21.2-31.2	26.2	Qal	7.1	10/89	5434.50	1.4
AI-GW-GS-34S	08/22/89 11/14/89 04/24/90	12.3-17.3	14.8	Qal	7.0	10/89	5434.60	1.1
AI-GW-GS-35D	08/17/89 11/08/89 04/20/90	23.5-33.5	28.5	Qal	12.5	10/89	5465.60	1.1
AI-GW-GS-35S	08/17/89 11/08/89 04/20/90	14.3-19.3	16.8	Qal	12.8	10/89	5466.60	2.1
AI-GW-GS-40	08/15/89 11/06/89 04/16/90	52-62	57	Qal	22.1	10/89	5481.30	1.4
AI-GW-GS-41D	08/15/89 11/08/89 04/16/90	50.5-60.5	55.5	Qal	33.4	10/89	5491.30	2.0
AI-GW-GS-41S	08/15/89 11/08/89 04/16/90	33.5-38.5	36	Qal	33.3	10/89	5491.90	2.5

Appendix IIIA. Area I Alluvial Groundwater Quality Data

IIIA--14

Well #	Water Qual Sampling		(umhos/cm)		(mV)	(ug/l)				(mg/l)
	Date	pH	SC	Eh	Al	As	Be	Cd	Ca	
AI-GW-GS-31S	08/23/89	6.5	894	150	<11.5	17.7	<1.0	5.5S	120	
	11/08/89	6.4	4525	90	150S	<3.0S	<1.0	3.0S	99.0S	
	04/19/90	6.4	1000		<22.0S	1.1S	<1.0	0.75S	136	
AI-GW-GS-32	08/23/89	6.1	2453	190	<11.5	5.6S	<1.0	40.9	492	
	11/08/89	5.8	2478	135	530S	<3.0S	<1.0	29.0	460	
	04/18/90	6.1	2807		74.3S	3.4S	<1.0	35.2	453	
AI-GW-GS-33	08/17/89	7.0	1775	160	<11.5	8.4S	2.4	12.8	167	
	11/08/89	6.4	1505	95	65.0S	8.5	<1.0	6.9	140S	
	04/20/90	7.0	1710		<22.0	12.9S	<1.0	5.0	163	
AI-GW-GS-34D	08/22/89	6.2	1012	150	54.8	<0.6	<1.0	53.1	103	
	11/14/89	6.3	983	190	71.0S	<3.0S	<1.0	19.0	71.0	
	04/24/90	6.4	1043		33.7	1.8S	<1.0	48.2S	86.4S	
AI-GW-GS-34S	08/22/89	5.6	1280	150	644	12.8	1.6	260	103	
	11/14/89	5.3	1232	190	610S	12.0S	<1.0	230	80.0	
	04/24/90	5.6	929		469	13.0S	<1.0	167S	68.1S	
AI-GW-GS-35D	08/17/89	6.4	1898	180	<11.5	<0.6S	<1.0	62.1	242	
	11/08/89	6.3	1090	145	<41.0S	<3.0S	<1.0	92.0	83.0S	
	04/20/90	6.1	1415		31.2	2.5S	<1.0	131S	136	
AI-GW-GS-35S	08/17/89	6.1	1310	180	42.0	0.7S	2.4	135	122	
	11/08/89	5.9	974	150	<41.0S	<3.0S	<1.0	110	80.0S	
	04/20/90	6.3	1176		28.2	1.9S	<1.0	141S	104	
AI-GW-GS-40	08/15/89	5.4	1170	180	188	0.6S	1.6	52.6	292	
	11/06/89	5.9	2543	210	180S	<3.0	<1.0	43.0	320S	
	04/16/90	5.6	2318		280S	1.1S	<1.0	48.5S	321S	
AI-GW-GS-41D	08/15/89	3.9	6835	120	71800	3.0S	40.8	1640	435	
	11/08/89	4.2	5780	250	63000	38.0S	28.0	1700	400S	
	04/16/90	3.9	7216		74700S	24.8S	37.2	1930S	382S	
AI-GW-GS-41S	08/15/89	3.8	6006	85	92400	21.6S	36.9	1780	387	
	11/08/89	4.1	5338	185	84000	63.0S	29.0	1700	340S	
	04/16/90	3.8	6361		103000S	43.4S	38.9	1800S	388S	

Well #	Water Qual Sampling		(ug/l)				(mg/l)			(ug/l)		
	Date	Cr	Co	Cu	Fe	Pb	Mg	Mn	Ni			
AI-GW-GS-31S	08/23/89	<2.8S	<2.6	5.8S	22.0	<0.5S	29.8	148	2.2S			
	11/08/89	<8.0S	26.0	14.0S	<12	<0.4S	34.0S	110S	<2.0			
	04/19/90	<8.0	<8.0	<4.0	<5	<0.5S	39.3	82	<1.3S			
AI-GW-GS-32	08/23/89	<2.8S	<2.6	48.9	25.0	<5.0S	112	367	52.1			
	11/08/89	<8.0	16.0	670S	<12S	<0.4S	110S	54S	31.0			
	04/18/90	<8.0	<8.0	714	<5S	4.0S	110	132	30.3S			
AI-GW-GS-33	08/17/89	<2.8	5.3	200.0S	11S	<0.5S	49.6S	320	4.6			
	11/08/89	<8.0S	28.0	140	<12	<0.4S	420S	63S	3.7			
	04/20/90	<8.0	<8.0	131	<5	0.6	44.2	27S	<1.3S			
AI-GW-GS-34D	08/22/89	<2.8S	15.6	509	597	<0.5S	27.7	18600	<13.9S			
	11/14/89	<8.0	<12.0	56.0	19S	0.4R	22.0S	14000S	8.9S			
	04/24/90	<8.0	14.9	541	<5S	0.6	22.4	16900S	20.6R			
AI-GW-GS-34S	08/22/89	<2.8S	30.9	12100	24600	179S	27.8	50300	13.9S			
	11/14/89	32.0	15.0	11000	22000	140S	26.0S	47000S	17.0			
	04/24/90	<8.0	21.6	7700	15000	122	17.8	30700S	17.0R			
AI-GW-GS-35D	08/17/89	<2.8	22.4	169S	35S	<0.5S	60.4S	44500	73.8S			
	11/08/89	14.0S	43.0	180	<12	<0.4S	24.0S	31000	70.0			
	04/20/90	<8.0	32.0	250	<5	<0.5	35.7	37800	106			
AI-GW-GS-35S	08/17/89	<2.8	51.1	55.3S	152	<0.5S	33.0S	37500	120S			
	11/08/89	19.0	66.0	90.0	72S	<0.4S	24.0S	34000S	88.0			
	04/20/90	<8.0	39.6	63.4	<5	<0.5	29.1	35700	120			
AI-GW-GS-40	08/15/89	<2.8	270	80.4S	42000	<0.5S	97.2S	114000	233S			
	11/06/89	87.0	310	120S	53000S	<0.4S	91.0	110000S	150			
	04/16/90	<8.0	335S	90.5S	57800S	<0.5S	103S	127000S	202S			
AI-GW-GS-41D	08/15/89	<2.8	1130	294000S	1800000	50.3	219S	153000	681S			
	11/08/89	85.0	1300	320000	1569950	120	210S	160000S	460			
	04/16/90	<8.0	1200S	338000S	2010000S	31.8S	206S	143000S	670S			
AI-GW-GS-41S	08/15/89	<2.8	810	492000S	1100000	101	169S	99800	613S			
	11/08/89	48.0S	960	52000	890000	93.0	170S	110000S	470			
	04/16/90	29.2	996S	540000S	1140000S	99.5S	176S	110000S	717S			

Appendix IIIA. Area I Alluvial Groundwater Quality Data

IIIA-16

Well #	Water Qual Sampling Date	(mg/l)			(ug/l)			(mg/l)					Total Alk (mg/l)
		K	Na		TI	Zn		Cl	F	Nitrate + Nitrite N	Sulfate		
AI-GW-GS-31S	08/23/89	6.58	31.7		20.0R	128		22.2	0.92	0.09	438		98
	11/08/89	6.60	36.0S		<9.0	46S		13.4	<0.10	3.58	428S		116S
	04/19/90	8.43	42.7		<2.0S	36S		20.0	0.37	3.60	390		88
AI-GW-GS-32	08/23/89	19.1	103		20.0R	7540		29.8	1.24	1.96	1930		<2
	11/08/89	17.0	100		<9.0	7200S		20.6	<0.10	1.52S	2080S		102S
	04/18/90	18.1	11.3		<2.0	6850		27.0	0.74	1.20S	1970S		95
AI-GW-GS-33	08/17/89	8.36	159S		<1.0S	382		127	1.70	14.7	192		310
	11/08/89	7.70	140S		<9.0	420		161	<0.10	13.7	401S		330
	04/20/90	8.53	150		<2.0	327S		160	0.52	10.0	310		300
AI-GW-GS-34D	08/22/89	7.53	79.5		20.0R	32600		43.1	1.89	3.07	453		65
	11/14/89	6.40	69.0		170	21000		35.9	1.20	2.70	414		76
	04/24/90	7.37	72.4		<2.0S	33500S		52.0S	1.80S	1.90S	460S		70
AI-GW-GS-34S	08/22/89	6.71	52.2		20.0R	151000		53.0	2.70	<0.05	778		<2
	11/14/89	5.80	41.0		480	140000		35.6	0.96	<0.01	676		<3S
	04/24/90	6.30	47.0		<2.0S	103000S		40.0S	1.70S	0.56S	550S		20
AI-GW-GS-35D	08/17/89	12.9	109S		<1.0S	12400		99.0	1.95	8.34	805		180
	11/08/89	10.0	46.0S		540	24000		48.7	0.74	8.61	427S		160
	04/20/90	13.4	55.9		<2.0	27500S		64.0	1.60	8.00	540		140
AI-GW-GS-35S	08/17/89	14.6	65.1S		<1.0S	32200		52.8	1.39	10.2	506		111
	11/08/89	13.0	49.0S		450	33000		40.9	0.82	8.44	397S		126S
	04/20/90	14.0	52.5		<2.0S	33200S		45.0	1.00	7.50	13.0		130
AI-GW-GS-40	08/15/89	19.4	31.7S		<1.0S	21200		8.9	2.84	0.18	1570		<1
	11/06/89	20.0S	31.0		1600	24000		4.0	1.62	<0.01S	2170		<3
	04/16/90	21.5	33.0S		<2.0S	19200S		8.0	0.86	<0.01S	1580		<5
AI-GW-GS-41D	08/15/89	14.8	75.8S		<1.0S	373000		21.9	14.1	0.11	10010		<1
	11/08/89	15.0	74.0S		2400	420000		18.0	18.0	0.39S	234		<3S
	04/16/90	16.4	75.1S		<10.0S	434000S		19.0	0.34	<0.01S	8690		<5
AI-GW-GS-41S	08/15/89	14.2	67.2S		<10.0	316000		60.9	14.6	<0.05	8050		<1
	11/08/89	14.0	60.0S		2100	360000		66.5	6.54	0.47S	8610		<3S
	04/16/90	15.0	66.3S		<10.0S	389000S		96.0	0.32	<0.01S	6650		<5

Well #	Water Qual Sampling Date	Depth (ft.) Screened Interval	Average Screened Depth	Probable Aquifer	Static Water Level	Date	Measuring Point Elevation (ft.)	MP Height from G.S. (ft.)
A1-GW-GS-42D	08/16/89	47.5-57.5	52.5	Qal	14.1	10/89	5471.10	1.7
	11/07/89							
	04/16/90							
A1-GW-GS-42S	08/16/89	13-18	15.5	Qal	13.8	10/89	5471.40	2.0
	08/16/89							
	11/07/89							
	04/17/90							
A1-GW-GS-43D	08/16/89	49-59	54	Qal	17.7	10/89	5475.00	0.0
	11/06/89							
	04/17/90							
A1-GW-GS-43S	08/16/89	18-23	20.5	Qal	17.4	10/89	5475.00	0.0
	11/06/89							
	04/17/90							
A1-GW-GS-44D	08/17/89	50.4-60.4	55.4	Qal	19.7	10/89	5476.20	0.0
	11/07/89							
	04/18/90							
A1-GW-GS-44S	08/17/89	19.7-24.7	22.2	Qal	19.0	10/89	5476.20	0.0
	11/07/89							
	04/18/90							
A1-GW-GS-45	08/15/89	49-59	54	Qal	31.4	10/89	5490.90	1.7
	11/06/89							
	04/16/90							
A1-GW-GS-46D	08/17/89	51-61	56	Qal	24.6	10/89	5484.00	0.0
	11/06/89							
	04/18/90							
A1-GW-GS-46S	08/17/89	24.5-29.5	27	Qal	25.0	10/89	5483.80	0.0
	11/06/89							
	04/18/90							
A1-GW-GS-50	08/21/89	248-268	258	Ts	25.0	10/89	5475.70	0.0
	11/06/89							

Appendix IIIA. Area I Alluvial Groundwater Quality Data

IIIA-18

Well #	Water Qual				(ug/l)				(mg/l) Ca
	Sampling Date	pH	SC (umhos/cm)	Eh (mV)	Al	As	Be	Cd	
AI-GW-GS-42D	08/16/89	4.2	3625	120	13300	1.6S	16.8	1010	423
	11/07/89	4.1	4492	280	14000	<3.0	15.0	960	460S
	04/16/90	4.0	2970		15300S	1.8S	14.4	1070S	433S
AI-GW-GS-42S	08/16/89	3.9	5567		111000	<6.0S	41.0	834	385
	08/16/89	3.7	5860		110000	<6.0S	42.1	842	386
	11/07/89				110000	33.0	29.0	920	390S
	04/17/90	3.6	7505		121000S	<3.5S	39.5	1350S	378S
AI-GW-GS-43D	08/16/89	5.1	2530		1030	<0.6S	<1.0	150	451
	11/06/89	5.3	3306	210	660	<3.0	<1.0	110	440S
	04/17/90	5.4	2100		552S	1.5S	<1.0	116S	358S
AI-GW-GS-43S	08/16/89	4.4	1930		8570	0.7S	11.1	533	274
	11/06/89	3.5	1980	290	9100	3.6	12.0	610	300S
	04/17/90	4.6	1440		9530S	6.3S	15.4	663S	301S
AI-GW-GS-44D	08/17/89	5.5	1084	220	382	<0.6S	1.6	91.7	120
	11/07/89	6.2	820	210	540	<3.0	1.5	100	83S
	04/18/90	5.3	898		513	1.1	1.5	102	96.8
AI-GW-GS-44S	08/17/89	5.3	339	230	686	<0.6S	2.1	25.4	29.3
	11/07/89	6.3	301	220	720	<3.0	1.3	36.0	24.0S
	04/18/90	4.8	390		1040	<0.7	2.2	41.2	31.4
AI-GW-GS-45	08/15/89	4.0	4100	200	56900	<6.0S	22.9	954	446
	11/06/89	4.2	4125	300	61000	53.0	20.0	1000	480S
	04/16/90	3.7	3738		77000S	7.0S	22.8	1170S	442S
AI-GW-GS-46D	08/17/89	6.3	557		20.1	<0.6S	<1.0	4.7	65.0
	11/06/89	6.5	653	200	140S	<3.0	<1.0	8.9	58.0S
	04/18/90	6.3	581		35.7S	1.2	<1.0	2.4S	62.6
AI-GW-GS-46S	08/17/89	6.7	357		238	<0.6S	1.6	10.0	36.4
	11/06/89	6.8	449		<41.0S	<3.0	<1.0	5.6	46.0S
	04/18/90	6.6	513		37.0S	1.3	<1.0	5.4S	52.6
AI-GW-GS-50	08/21/89	7.2	1214	130	56.9	15.8	<1.0	3.4S	
	11/06/89	7.2	2268	165	83.0S	18.0	<1.0	3.0S	100S

Well #	Water Qual Sampling		(ug/l)				(mg/l)				(ug/l)		
	Date	Cr	Co	Cu	Fe	Pb	Mg	Mn	Ni				
AI-GW-GS-42D	08/16/89	<2.8	1580	68200S	98200	29.3S	170S	352000	506S				
	11/07/89	150	1900	81000	130000S	81.0	180	360000S	400				
	04/16/90	<8.0	1970S	67400S	151000S	18.0S	164S	396000S	673S				
AI-GW-GS-42S	08/16/89	<2.8	648	279000S	173000	30.9S	230S	110000	415S				
	08/16/89	<2.8	639	285000S	177000	31.3S	239S	112000	422S				
	11/07/89	53.0S	740	350000	1581210	150	180S	100000S	250				
	04/17/90	<8.0	818S	293000S	2410000S	17.5S	212S	108000S	478S				
AI-GW-GS-43D	08/16/89	<2.8	775	2240S	31700	<0.5S	152S	142000	270S				
	11/06/89	100	810	1200	36000S	<0.4S	110	120000S	210				
	04/17/90	<8.0	636S	938S	36500S	2.0S	108S	114000S	258S				
AI-GW-GS-43S	08/16/89	<2.8	377	15100S	219S	12.0S	61.8S	64400	223S				
	11/06/89	50.0S	420	17000	340S	12.0	56.0	67000S	200				
	04/17/90	<8.0	405S	15000S	164S	7.0S	61.3S	73800S	313S				
AI-GW-GS-44D	08/17/89	<2.8	175	3110S	30S	<0.5S	34.1S	33400	157S				
	11/07/89	17.0S	230	4600	210	<0.4S	26.0S	34000S	110				
	04/18/90	<8.0	197	3930	71S	<0.5S	28.9	31500	137				
AI-GW-GS-44S	08/17/89	<2.8	34.9	1980S	106S	<0.5S	7.56S	5670	23.2				
	11/07/89	<8.0S	47.0	2000	45S	2.2S	6.60S	7000S	29.0				
	04/18/90	<8.0	45.7	2790	19S	0.9S	8.48	6950	3.4S				
AI-GW-GS-45	08/15/89	<2.8	2760	79600S	198S	7.7S	164S	219000	526S				
	11/06/89	140	2700	93000	85S	<0.4S	120	200000S	380				
	04/16/90	<8.0	2600S	78000S	430S	<0.5S	104S	192000S	526S				
AI-GW-GS-46D	08/17/89	<2.8	3.8	11.8S	107S	<0.5S	17.7S	132	2.8				
	11/06/89	<8.0S	15.0	15.0S	<12.0S	<0.4S	17.0	62S	2.5				
	04/18/90	<8.0	<8.0	16.8	<5S	<0.5S	17.2	3	2.6				
AI-GW-GS-46S	08/17/89	<2.8	<2.6	221S	130S	0.9S	10.5S	543	8.8				
	11/06/89	<8.0S	<12.0	19.0S	23.0S	<0.4S	14.0	68S	4.5				
	04/18/90	<8.0	<8.0	23.5	<5S	<0.5S	14.7	4	6.0				
AI-GW-GS-50	08/21/89	<2.8	2.8	8.7	115S	<0.5S	18.0	262	2.6S				
	11/06/89	<8.0S	<12.0	13.0S	33.0S	<0.4S	18.0	190S	2.6				

Appendix IIIA. Area I Alluvial Groundwater Quality Data

IIIA-20

Well #	Water Qual Sampling		(mg/l)			(ug/l)			(mg/l)					(mg/l)
	Date		K	Na		Tl	Zn		Cl	F	N	Sulfate		
AI-GW-GS-42D	08/16/89		21.7	91.7S		13.4	220000		33.8	7.94	0.07	5500	Total Alk	
	11/07/89		23.0S	100		4900	280000		26.4	3.74	0.25S	2170	<1	
	04/16/90		23.2	94.4S		<2.0S	245000S		35.0	0.42	<0.01S	3190	<3	
AI-GW-GS-42S	08/16/89		15.4	79.4S		<1.0S	200000		52.9	12.1	<0.05	11400	<1	
	08/16/89		14.6	75.9S		<1.0S	223000		53.0	12.4	<0.05	11500	<1	
	11/07/89		14.0	72.0S		1200	290000		43.4	4.60	0.27S	2340	<3S	
	04/17/90		14.5	79.2S		<2.0S	280000S		37.0	0.21	<0.01S	8920	<5	
AI-GW-GS-43D	08/16/89		27.4	50.3S		14.2	44600		32.5	3.87	<0.05	2680	<1	
	11/06/89		23.0S	39.0		200	54000		22.3	<0.10	<0.01S	3230	<3	
	04/17/90		22.5	37.4S		<2.0S	37400S		26.0	0.52	0.12S	1910	<5	
AI-GW-GS-43S	08/16/89		19.7	40.1S		<10.0	73500		24.8	6.47	0.30	1632	<1	
	11/06/89		17.0S	41.0		920	96000		7.7	2.70	12.4	1970	<3	
	04/17/90		19.1	40.2S		<2.0S	80100S		16.0	0.72	13.0S	1280	<5	
AI-GW-GS-44D	08/17/89		9.33	26.2S		12.5	23300		14.3	1.52	2.01	561	16	
	11/07/89		6.50	21.0S		560	25000		23.1	7.92	1.40	532	32S	
	04/18/90		7.94	23.7		<2.0	23500		16.0	1.10	0.91S	430S	8	
AI-GW-GS-44S	08/17/89		3.72	14.4S		<1.0S	7520		19.2	1.12	5.53	121	8	
	11/07/89		3.30	11.0S		91.0	8300		16.2	0.82	8.33	125	27S	
	04/18/90		4.65	13.9		<2.0	9680		18.0	1.10	8.50S	200S	<5	
AI-GW-GS-45	08/15/89		25.0	93.3S		<10.0	171000		47.4	15.3	7.16	3930	<1	
	11/06/89		23.0S	87.0		4100	250000		42.2	9.75	7.84	4160	<3	
	04/16/90		17.1	85.5S		<2.0S	192000S		53.0	0.36	12.0S	2350	<5	
AI-GW-GS-46D	08/17/89		5210	30.1S		<1.0S	444		28.1	0.26	10.1	117	<1	
	11/06/89		5.30S	29.0		<9.0	430		18.8	<0.10	10.2	117	117	
	04/18/90		4.03	28.8		<2.0	339		25.0	0.20	11.0S	140S	100	
AI-GW-GS-46S	08/17/89		4.40	24.6S		<1.0S	1750		9.8	0.37	5.26	53.4	106	
	11/06/89		5.10S	27.0		19.0	1000		14.0	0.29	6.05	44.7	135	
	04/18/90		3.87	31.9		<2.0	823		19.0	0.36	6.00S	61.0S	190	
AI-GW-GS-50	08/21/89		15.4	99.6		20.0R	799		21.7	2.06	0.15	486	100	
	11/06/89		17.0S	90.0		<9.0	770		18.0	1.36	0.29S	1290	109	

Appendix IIIA. Area I Alluvial Groundwater Quality Data

IIIA-21

Well #	Water Qual Sampling Date	Depth (ft.) Screened Interval	Average Screened Depth	Probable Aquifer	Static Water Level	Date	Measuring Point Elevation (ft.)	MP Height from G.S. (ft.)
AI-GW-GS-50	04/16/90	248-268	258	Ts	25.0	10/89	5475.70	0.0
AI-PW-04	11/08/89 11/08/89	9.5-19.5	14.5	Qal	7.0	10/89	0.00	3.0
AI-PW-01	11/15/89	17-42	29.5	Qal	21.2	9/89	0.00	2.5
AMC-06	04/17/90				33.9	9/89	5493.40	1.9
AMC-08	04/17/90				61.9	9/89	5525.60	2.0
AMC-12	11/08/89 04/17/90	35-45	40	Qal	21.3	9/89	5480.10	2.0
AMC-13	08/24/89 11/06/89 04/18/90	47-55	51	Qal	19.7	9/89	5475.30	2.4
AMC-23	11/08/89 04/19/90	19-29	24	Qal	5.4	03/28/85	5448.30	1.8
AMC-24	11/08/89 04/18/90	13-23	18	Qal	9.3	03/28/85	5452.10	1.9
BMW-1B	04/20/90				7.0	07/12/89	5433.90	0.7
BMW-2A	04/24/90				5.8	06/28/89	5423.70	1.2
BMW-2B	04/24/90				7.1	07/12/89	5424.20	1.0
BMW-2T	04/24/90				6.5	07/12/89	5423.80	1.3
BMW-4A	11/09/89 04/24/90	5.5-11.5	8.5	Qal	2.7	07/12/89	5416.00	0.7
BMW-4B	11/09/89 04/24/90	27.5-37.5	32.5	Tqm	4.0	07/12/89	5419.30	0.6
BMW-4T	11/15/89 11/15/89 04/24/90 04/24/90	2.0-4.0	3	Tailings	3.5	07/12/89	5418.90	1.0
BMW-6B	11/09/89 04/25/90	59.0-79.0	69	Tqm	10.2	07/12/89	5426.10	0.9
BMW-7A	04/19/90				2.3	07/12/89	5435.70	1.6

Appendix IIIA. Area I Alluvial Groundwater Quality Data

IIIA-22

Well #	Water Qual										(mg/l)		
	Sampling Date	pH	SC (umhos/cm)	Eh (mV)	Al	As	Be (ug/l)	Cd	Ca				
AI-GW-GS-50	04/16/90	7.3	1125		40.7S	33.6S	<1.0	2.1S	129S				
AI-PW-04	11/08/89	3.8	1863	210	2600	1600	1.9	180	130S				
	11/08/89	3.7	1912	190	2500	1800	1.5	170	110S				
AI-PW-01	11/15/89	6.7	863	135									
AMC-06	04/17/90	6.5	1460		<22.0S	1.3S	<1.0	3.0S	175S				
AMC-08	04/17/90	6.0	418		38.5S	<0.7	<1.0	0.84S	50.1				
AMC-12	11/08/89	5.2	2986		550	<3.0	1.8	290	340S				
	04/17/90	5.5	2760		684S	1.7S	1.5	352S	380S				
AMC-13	08/24/89	6.3	1410	60	<11.5	2.8S	1.7	13	229				
	11/06/89	6.1	1093	170	100S	<3.0	<1.0	5.9	210S				
	04/18/90	6.1	1434		53.7S	0.9S	<1.0	8.8S	192				
AMC-23	11/08/89	6.6	2776		<41.0S	<3.0	<1.0	18.0	360S				
	04/19/90	6.2	2245		<22.0	1.9S	<1.0	17.8	382				
AMC-24	11/08/89	6.6	1413	120	<41.0S	5.3S	<1.0	2.4S	140S				
	04/18/90	6.7	1290		56.5S	26.5	<1.0	0.57S	160				
BMW-1B	04/20/90	7.3	1080		<22.0	4.8S	<1.0	0.08S	123				
BMW-2A	04/24/90	3.7	2218		5450	2950	6.7	297S	209				
BMW-2B	04/24/90	3.9	4050		16700	4900	10.3	674S	387				
BMW-2T	04/24/90	2.6	3576		113000	1310	4.9	1840S	115				
BMW-4A	11/09/89	4.0	1922	180	9500	2300	2.3	260	130				
	04/24/90	3.9	2162		11800	2100S	3.1	316S	181				
BMW-4B	11/09/89	5.0	2246	180	4000	630	3.5	410	210				
	04/24/90	4.5	2050		4560	2040	4.5	410S	196				
BMW-4T	11/15/89	5.8	2032	165	900S	130	<1.0	140S	310				
	11/15/89	5.0	1914	200	7200	1700	2.1	250S	220				
	04/24/90	3.4	2397		10700	1090	1.4	294S	193				
	04/24/90	3.2	2430		10900	750	1.9	301S	192				
BMW-6B	11/09/89	5.5	2698	220	1300	<3.0	3.0	210	280				
	04/25/90	5.5	2950		991	<0.7S	2.7	217S	381				
BMW-7A	04/19/90	6.5	653		<22.0	2.2S	<1.0	22.0	81.9				

Well #	Water Qual Sampling										(ug/l)		
	Date	Cr	Co	Cu	Fe	Pb	Mg	Mn	Ni		(mg/l)		
AI-GW-GS-50	04/16/90	<8.0	<8.0S	<4.0S	28.0S	<0.5S	19.6S	75S	2.2				
AI-PW-04	11/08/89	12.0S	42.0	14000	41000	460	28.0S	15000S	19.0				
	11/08/89	13.0S	49.0	13000	33000	650	25.0S	15000S	25.0				
AI-PW-01	11/15/89												
AMC-06	04/17/90	<8.0	<8.0S	<4.0S	13000S	<0.5S	39.5S	13400S	58.4S				
AMC-08	04/17/90	<8.0	<8.0	4.2	18S	<0.5S	13.5	190	1.9S				
AMC-12	11/08/89	87.0	790	1600	11000	<0.4S	98.0S	120000S	250				
	04/17/90	<8.0	719S	1290S	12000S	<0.5S	107S	124000S	348S				
AMC-13	08/24/89	<2.8S	<2.6	<1.1S	3480S	<0.5S	53.6	19500	72.5				
	11/06/89	<9.0S	18.0	12.0S	4300S	<0.4S	53.0	18000S	51.0				
	04/18/90	<8.0	<8.0	<4.0	3250	<2.5S	59.8	18600	71.5				
AMC-23	11/08/89	<8.0S	13.0	100S	1900	<0.4S	86.0S	95S	11.0				
	04/19/90	<8.0	<8.0	65.9	1600	<2.5S	93.8	60	17.3S				
AMC-24	11/08/89	<8.0S	18.0	16.0S	2600	<0.4S	43.0S	1300S	4.6				
	04/18/90	<8.0	<8.0	7.5	2520	<0.5S	48.8	1390	3.1				
BMW-1B	04/20/90	<8.0	<8.0	<4.0	<5	<0.5	30.3	<2S	<1.3S				
BMW-2A	04/24/90	<8.0	151	20300	131000S	160	45.9	61500	102				
BMW-2B	04/24/90	<8.0	376	58500	283000S	7.5	108	152000	224				
BMW-2T	04/24/90	<8.0	114	408000	217000S	39.6	23.7	25800	172				
BMW-4A	11/09/89	27.0	72.0	25000S	100000	260	35.0S	34000	37.0				
	04/24/90	<8.0	96.0	28100	109000S	204	41.7	40700	80.5				
BMW-4B	11/09/89	25.0	120	11000S	220000	63.0	49.0S	40000	58.0				
	04/24/90	<8.0	127	12500	206000S	86.7	42.5	37800	101				
BMW-4T	11/15/89	<8.0	59.0	7600S	200000	<0.4S	54.0S	57000	23.0				
	11/15/89	29.0	28.0	20000S	170000	250S	47.0S	50000	39.0				
	04/24/90	<8.0	85.3	34700	102000S	690	41.7	45600	66.5				
	04/24/90	<8.0	90.8	35800	100000S	590S	41.4	45500	69.7				
BMW-6B	11/09/89	20.0	150	11000S	15000	<0.4S	89.0S	43000	78.0				
	04/25/90	<8.0	110	6910	11300S	<0.5S	107	40900	138				
BMW-7A	04/19/90	<8.0	<8.0	28.7	<5	2.5	21.0	8900	4.4S				

Appendix IIIA. Area I Alluvial Groundwater Quality Data

IIIA-24

Well #	Water Qual Sampling Date	(mg/l)		(ug/l)			(mg/l)					Total Alk (mg/l)
		K	Na	TI	Zn	Cl	F	N	Sulfate			
AI-GW-GS-50	04/16/90	17.6	111S	<2.0S	211S	21.0	2.00	0.36S	440			100
AI-PW-04	11/08/89	4.50	86.0S	200	74000	28.3	0.63	<0.01S	2150S			<3S
	11/08/89	4.80	82.0S	170	67000	23.8	0.62	<0.01S	1190S			<3S
AI-PW-01	11/15/89					23.9	<0.10	1.15S	256			301
AMC-06	04/17/90	6.13	25.8S	<2.0S	4310S	15.0	0.41	0.94S	610			45
AMC-08	04/17/90	4.06	13.6	<2.0	321	20.0	0.16	4.60S	120S			50
AMC-12	11/08/89	18.0	39.0S	2200	90000	19.0	2.29	<0.01S	2380			27S
	04/17/90	20.1	44.4S	<2.0S	69300S	20.0	1.10	0.02S	1790			5
AMC-13	08/24/89	5.42S	25.8	2.0R	3560	14.9	0.23	0.57	910			31
	11/06/89	7.70S	29.0	330	2800	12.5	<0.10	0.59S	795			<3
	04/18/90	7.97	32.0	<2.0	2670	16.0	0.19	0.63S	780S			35
AMC-23	11/08/89	13.0	86.0S	<9.0	3600	67.8	1.14	5.50	1400S			131S
	04/19/90	15.3	92.0	<2.0	3630	70.0	0.68	5.60	1230			120
AMC-24	11/08/89	8.80	48.0S	<9.0	330	14.0	<0.10	2.05	642S			104S
	04/18/90	10.0	53.2	<2.0	358	19.0	0.50	2.00S	520S			90
BMW-1B	04/20/90	7.79	61.9	<2.0	10S	42.0	0.17	23.0	190			240
BMW-2A	04/24/90	8.53	88.6	<2.0S	118000S	33.0S	1.80S	0.02S	1360S			<5
BMW-2B	04/24/90	16.0	96.1	<10.0S	298000S	40.0S	0.99S	<0.01S	5320S			<5
BMW-2T	04/24/90	1.34	52.9	6.5	97500S	22.0S	0.35S	0.07S	3480S			<5
BMW-4A	11/09/89	6.70	100	380	86000S	23.3	0.93	<0.01S	1630			<3S
	04/24/90	6.18	122	<2.0S	109000S	33.0S	1.60S	<0.01S	1260S			<5
BMW-4B	11/09/89	10.0	58.0	360	120000S	17.9	1.22	<0.01S	2180			<3S
	04/24/90	9.70	74.0	<2.0S	117000S	31.0S	1.90S	<0.01S	1330S			<5
BMW-4T	11/15/89	7.80	73.0S	560	64000	23.4	2.00	<0.01S	1860			<3S
	11/15/89	5.70	76.0S	470	95000	23.3	2.34	<0.01S	1820			<3S
	04/24/90	4.54	91.3	<2.0S	105000S	33.0S	1.40S	<0.01S	1400S			<5
04/24/90	4.27	91.3	<2.0S	107000S	34.0S	1.50S	<0.01S	1610S			<5	
BMW-6B	11/09/89	8.20	93.0	480	73000	65.3	1.74	5.01	1860			34S
	04/25/90	9.85	130	<2.0S	69400S	85.0S	1.80S	3.80S	2010S			20
BMW-7A	04/19/90	7.12	38.1	<2.0	1880S	54.0	1.00	6.20	120			100

Well #	Water Qual Sampling Date	Depth (ft.) Screened Interval	Average Screened Depth	Probable Aquifer	Static Water Level	Date	Measuring Point Elevation (ft.)	MP Height from G.S. (ft.)
BMW-7B	04/19/90				2.3	07/12/89	5435.60	1.0
BMW-9B	04/19/90							
BMW-10A	11/09/89 04/19/90	4.0-7.0	5.5	Qal	5.0	07/12/89	5437.70	2.3
BMW-11B	04/20/90				10.9	09/15/89	0.00	1.0
BMW-13B	04/20/90				5.3	09/15/89	0.00	0.9
CT-84-10	11/10/89 11/10/89							
MF-04	11/09/89			Qal	14.3	03/28/85	5459.70	0.5
MP-07	11/15/89	6-16		Qal	3.6	03/28/85	0.00	-0.4
AI-DW-01	08/25/89 11/06/89 04/18/90							
AI-DW-02	08/25/89 11/14/89 04/17/90 04/17/90							
AI-DW-03	11/15/89							
AI-DW-04	04/19/90 04/19/90							
AI-DW-132	04/20/90 04/20/90							

Well #	Water Qual										(mg/l) Ca
	Sampling Date	pH	(umhos/cm) SC	(mV) Eh	Al	As	Be	Cd			
BMW-7B	04/19/90	6.5	689		<22.0	6.4S	<1.0	23.8		59.3	
BMW-9B	04/19/90	7.0	895		<22.0	47.5S	<1.0	<0.03S		101	
BMW-10A	11/09/89	6.2	1263	230	580S	6.6	<1.0	220		110	
	04/19/90	6.8	1220		<22.0	8.3S	<1.0	69.0		178	
BMW-11B	04/20/90	7.3	1271		<22.0	5.2S	<1.0	0.17		98.0	
BMW-13B	04/20/90	7.0	900		24.5	3.0S	<1.0	0.36S		112	
CT-84-10	11/10/89	4.5	1395	210	1900	1100	<1.0	140		120	
	11/10/89	4.6	1427	210	1900	2000	<1.0	150		130	
MF-04	11/09/89	7.0	1757	100	220S	<3.0S	<1.0	1.4S		130	
MP-07	11/15/89	6.3	784	110	140S	3.8S	<1.0	2.2S		110	
AI-DW-01	08/25/89	5.7	1030	-40	946	2.5S	6.6	245		156	
	11/06/89	3.4	1237	260	1200	<3.0	2.8	380		140S	
	04/18/90	5.6	1260		478	<0.7S	2.4	377		128	
AI-DW-02	08/25/89	6.4	576	30	<11.5S	<0.6S	1.7	1.2S		78.4	
	11/14/89	6.8	565	180	230S	<3.0S	<1.0	1.0S		59.0	
	04/17/90	6.4	652		<22.0S	<0.7S	<1.0	0.38S		75.7S	
	04/17/90	6.5	650		<22.0S	<0.7S	<1.0	0.44S		76.3S	
AI-DW-03	11/15/89	6.9	372	75	170S	<3.0	<1.0	0.8S		62.0	
AI-DW-04	04/19/90	7.0	1421		59.1S	16.5	<1.0	2.20S		165	
	04/19/90	6.7	1421		79.7S	32.6	<1.0	3.00S		166	
AI-DW-132	04/20/90	6.3	1137		27.8	5.3S	<1.0	106		119	
	04/20/90	6.2	1123		24.3	6.8S	<1.0	110		123	

Well #	Water Qual Sampling		(ug/l)				(mg/l)			(ug/l)		
	Date	Cr	Co	Cu	Fe	Pb	Mg	Mn	Ni			
BMW-7B	04/19/90	<8.0	<8.0	<4.0	<5	<0.5S	15.5	9120	1.3S			
BMW-9B	04/19/90	<8.0	<8.0	<4.0	777	<0.5	25.8	1300	<1.3S			
BMW-10A	11/09/89	<8.0	42.0	1400S	94S	<2.7S	31.0S	33000	20.0			
	04/19/90	<8.0	<8.0	2520	<5	4.4	40.0	6040	9.0S			
BMW-11B	04/20/90	<8.0	<8.0	<4.0	<5	0.6	27.1	<2S	<1.3S			
BMW-13B	04/20/90	<8.0	<8.0	<4.0	<5	<0.5	27.1	218	<1.3S			
CT-84-10	11/10/89	<8.0	28.0	8200S	17000	400	28.0S	12000	8.0			
	11/10/89	<8.0	23.0	7800S	17000	390	26.0S	13000	10.0			
MF-04	11/09/89	<8.0	20.0	<6.0S	52S	<0.4S	51.0S	41S	<2.0			
MP-07	11/15/89	<8.0	<12.0	<6.0S	69S	<0.4S	30.0S	1600	2.0			
AI-DW-01	08/25/89	<2.8	293	2950S	14700	24.1	44.0	48600S	204			
	11/06/89	32.0S	280	4500	8500	160	39.0	43000S	170			
	04/18/90	<8.0	244	1150	12800	<0.5S	36.7	38800	206			
AI-DW-02	08/25/89	<2.8	<2.6	30.0S	10	<0.5S	19.3	53S	<1.1S			
	11/14/89	<8.0	<12.0	8.0	20S	0.4R	17.0S	54S	<2.0S			
	04/17/90	<8.0	<8.0S	<4.0	16S	0.8S	17.9S	29S	<1.3			
	04/17/90	<8.0	<8.0S	32.2S	11S	1.5S	18.0S	23S	<1.3			
AI-DW-03	11/15/89	<8.0	<12.0	<6.0S	29S	<0.4S	14.0S	9	<2.0			
AI-DW-04	04/19/90	<8.0	<8.0	9.1	22S	<0.5S	45.9	1650	<1.3S			
	04/19/90	<8.0	<8.0	31.1	110S	<0.5S	45.8	1650	1.7			
AI-DW-132	04/20/90	<8.0	<8.0	785	<5	13	25.2	22500	11.5S			
	04/20/90	<8.0	8.5	810	<5	15.6S	26.1	23500	14.0S			

Appendix IIIA. Area I Alluvial Groundwater Quality Data

IIIA-28

Well #	Water Qual Sampling Date	(mg/l)			(ug/l)			(mg/l)					Total Alk (mg/l)
		K	Na		TI	Zn		Cl	F	N	Sulfate		
BMW-7B	04/19/90	9.59	76.6		<2.0	1120S		43.0	0.86	4.30	170	100	
BMW-9B	04/19/90	6.04	80.6		<2.0	49S		28.0	0.69	0.07S	320	140	
BMW-10A	11/09/89	7.00	45.0		390	73000S		21.0	1.77	0.68S	579	128S	
	04/19/90	7.81	58.2		<2.0S	18700S		24.0	1.50	1.40S	360	200	
BMW-11B	04/20/90	4.49	142		<2.0S	18S		37.0	1.40	6.30	340	160	
BMW-13B	04/20/90	6.28	58.2		<2.0	438S		29.0	0.54	1.50S	290	170	
CT-84-10	11/10/89	3.70	76.0		130	51000S		29.1	0.62	<0.01S	1170	<3S	
	11/10/89	3.90	79.0		150	53000S		31.4	0.60	<0.01S	1200	<3S	
MF-04	11/09/89	6.30	120		<9.0	47S		137	<0.10	14.3	199	473	
MP-07	11/15/89	6.10	40.0S		15.0	35S		18.3	<0.10	0.95S	354	238	
AI-DW-01	08/25/89	8.64S	28.5		2.0R	29100		15.2	2.18	<0.05	184	<2	
	11/06/89	13.0S	27.0		750	36000		7.8	0.99	<0.01S	834	10	
	04/18/90	7.21	27.5		<2.0	23500		14.0	1.20	0.03S	620S	20	
AI-DW-02	08/25/89	4.22S	21.1		20.0R	581		35.9	0.48	15.2	155	68	
	11/14/89	4.00	19.0		<9.0	490		17.0	0.28	15.10S	152	83	
	04/17/90	4.10	19.7S		<2.0S	421S		20.0	0.30	16.0S	130	80	
AI-DW-03	04/17/90	4.17	19.7S		<2.0S	530S		19.0	0.28	16.0S	120	83	
	11/15/89	4.10	18.0S		<9.0	82		10.1	0.34	7.60S	57.9	160	
AI-DW-04	04/19/90	9.62	76.9		<2.0	55		84.0	0.98	5.70S	400S	320	
	04/19/90	9.56	76.1		<2.0	69		83.0	1.30	5.90S	330S	310	
AI-DW-132	04/20/90	9.90	56.1		<2.0S	39900S		39.0	2.30	1.60S	570	110	
	04/20/90	10.2	58.6		<2.0	41200S		39.0	2.20	1.70S	540	110	

Sources: 1985-1986 data: MultiTech, April 1987, Appendix B, Part 2, Attachments II and VI.	
1989-1990 data: CH2M Hill and Chen-Northern, 1990, Volume II, Appendix B and Addendum.	
LEGEND	
R = value unuseable because quality control criteria were not met.	
S = screening level data.	

Appendix IIIB. Alluvial Groundwater Quality Data: Leach Pads Area.

IIIB-1

Well ID:	Sampling Dates	Screened Interval (ft)	Temp (C)	Field Conductivity (umhos/cm)	Field pH (SU)	Field Eh (mV)	Aluminum	Arsenic	Barium	Cadmium	Calcium	Chromium
LP-01	Apr 91	175-195	14.2 E	2143 E	5.6 E	273 E	0.624 E	0.0007 R	0.0443 S	0.287 E	385 E	0.0018 E
	July 91		16.8 E	1920 E	5.49 E	301 E	0.497 E	0.0016 E	0.0421 S	0.274 E	380 E	0.0031 US
	May 92		11.8	1600	5.54	279	0.354 E	0.001 UE	0.0428 S	0.232 E	389 E	0.004 UE
LP-02	Apr 91	127-157	13.8 E	6365 E	4.81 E	351 E	39.7 E	0.0007 R	0.192 S	4.07 E	327 E	0.0018 E
	July 91		14.8 E	6100 E	4.42 E	333 E	63.2 E	0.01 UE	0.216 S	3.82 E	317 E	0.0119 UE
	May 92		14.4	4300	4.1	320	109 E	0.002 US	0.029 US	2.39 E	304 E	0.0188 E
LP-03	Apr 91	30-50	15.7 E	13270 E	3.14 E	310 E	1110 E	0.014 R	0.483 S	5.94 E	396 E	0.0529 E
	July 91		16 E	11000 E	3.23 E	312 E	1210 E	0.02 UE	0.541 S	5.25 E	377 E	0.0897 E
	May 92		16.1	11900	3.44	297	1380 E	0.136 S	0.0179 US	5.03 E	385 E	0.153 E
	May 92(T)		16.1	11900	3.44	297	1160	0.0406	0.0094	5.15	352	0.122
	May 92(T)		16.1	11900	3.44	297	1370	0.01	0.0171	4.31	317	0.118
LP-04	Apr 91	125-145	12.2 E	3100 E	5.71 E	291 E	0.323 E	0.0007 R	0.0412 S	0.237 E	611 E	0.0018 E
	July 91		14 E	2810 E	5.43 E	295 E	0.284 E	0.0014 E	0.0421 S	0.27 E	545 E	0.0024 US
	May 92		13.1	2900	5.63	304	0.142 UE	0.001 US	0.0359 S	0.382 E	480 E	0.004 UE
LP-05	Apr 91	186-226	13.2 E	1386 E	5.55 E	278 E	0.461 E	0.0007 R	0.0235 S	0.0442 E	211 E	0.0018 E
	Apr 91(D)		13.2 E	1386 E	5.55 E	278 E	0.466 E	0.0007 R	0.0223 S	0.044 E	210 E	0.0018 E
	July 91		17.9 E	1220 E	5.52 E	263 E	0.366 E	0.0011 E	0.0211 S	0.0446 E	219 E	0.0024 UE
	July 91(D)		17.9 E	1220 E	5.52 E	263 E	0.398 E	0.001 UE	0.0224 S	0.051 E	240 E	0.0024 UE
	May 92		12.5	1100	5.45	264	0.182 E	0.001 UE	0.019 E	0.0426 E	200 E	0.004 UE
LP-06	Apr 91	90-110	8.2 E	1088 E	8.41 E	177 E	0.204 E	0.0098 R	0.086 S	0.0018 E	94.7 E	0.0018 E
	July 91		13 E	960 E	8.45 E	148 E	0.117 E	0.008 E	0.077 S	0.002 UE	94.6 E	0.0024 UE
	May 92		12.1	980	8.01	203	0.013 E	0.001 UE	0.0826 E	0.002 UE	105 E	0.004 UE
LP-07	May 92	90-95	13.5	12000	3.68	340	1160 E	0.106 S	0.0336 S	9.95 E	333 E	0.111 E
	May 92 (D)		13.5	12000	3.68	340	1170	0.01	0.0362	10.5	359	0.115
	Aug 92		13.5	14467	3.50	408	957 E	0.01 US	0.0313 E	10.4 E	382 E	0.0459 E
	Aug 92 (T)		13.5	14467	3.50	408	939	0.0105	0.024	9.33	361	0.032
	Aug 92 (T)		13.5	14467	3.50	408	960	0.01	0.0313	10.5	388	0.0519
LP-08	May 92	79-94	12.2	12400	3.73	345	1510 E	0.02 UE	0.0309 US	6.76 E	349 E	0.0797 E
	Aug 92		13.3	14019	3.38	358	1780 E	0.02 US	0.0338 E	9.58 E	396 E	0.0859 E

Appendix IIIB. Alluvial Groundwater Quality Data: Leach Pads Area.

IIIB-2

Well ID:	Sampling Dates	Screened Interval (ft)	Temp (C)	Field Conductivity (umhos/cm)	Field pH (SU)	Field Eh (mV)	Al Aluminum	As Arsenic	Ba Barium	Cd Cadmium	Ca Calcium	Cr Chromium
LP-09	May 92	80-100	10	3550	5.77	288	0.0604 UE	0.001 US	0.019 US	0.458 E	400 E	0.004 UE
	Aug 92		11.8	4036	5.53	237	0.0933 E	0.001 US	0.0178 S	0.507 E	443 E	0.004 UE
LP-10	May 92	130-160	15	310	5.50	294	0.225 E	0.001 UE	0.0129 E	0.0042 E	42.6 E	0.004 UE
	Aug 92		12.5	372	5.68	265	0.195 E	0.001 UE	0.0139 E	0.002 UE	47.3 E	0.004 UE
LP-12	May 92	107-127	10.5	800	5.83	283	0.036 UE	0.001 UE	0.0162 E	0.0142 E	160 E	0.004 UE
	Aug 92		10.3	853	5.46	161	0.015 UE	0.001 UE	0.0139 E	0.0138 E	154 E	0.004 UE
LP-13	May 92	216.5-236.5	11.8	520	5.37	285	0.0295 UE	0.001 UE	0.021 E	0.0044 E	89.1 E	0.004 UE
	Aug 92		11.5	655	5.02	195	0.0232 E	0.001 UE	0.0156 E	0.0078 E	88.9 E	0.004 UE
	Aug 92(D)		11.5	655	5.02	195	0.0387	0.001	0.0147	0.007	88.4	0.004
LP-14	May 92	82.5-102.5	8.7	800	6.08	303	0.013 UE	0.001 UE	0.0362 E	0.0097 E	192 E	0.004 UE
	Aug 92		9.7	1222	5.87	245	0.015 UE	0.001 UE	0.0373 E	0.0112 E	231 E	0.004 UE
LP-15	May 92	215-235	12.3	500	6.59	257	0.0193 UE	0.001 E	0.0114 E	0.0052 E	84.5 E	0.004 UE
	Aug 92		11.1	660	6.03	270	0.015 UE	0.0011 E	0.0116 E	0.0045 E	84.2 E	0.004 UE
LP-16	May 92	100-120	11.2	1050	5.90	251	0.0212 UE	0.001 UE	0.0155 E	0.0187 E	22.5 E	0.004 UE
	Aug 92		9.8	1328	6.20	292	0.0242 E	0.001 UE	0.0165 E	0.0171 E	229 E	0.004 UE

Well ID:	Sampling Dates	Cu Copper	Fe Iron	Pb Lead	Mg Magnesium	Mn Manganese	Hg Mercury	Ni Nickel	K Potassium	Ag Silver
LP-01	Apr 91	2.03 E	0.191 E	0.0089 R	103 E	0.0448 E	0.0001 E	0.23 S	13.1 E	0.0028 R
	July 91	2.44 E	0.0747 UE	0.036 S	104 E	0.0261 UE	0.0001 R	0.225 E	13 E	0.0024 R
	May 92	3.14 E	0.156 E	0.0181 E	110 E	0.0213 UE	0.0002 UE	0.197 E	9.94 S	0.002 UE
LP-02	Apr 91	74.4 E	0.147 E	0.0021 R	656 E	167 E	0.00014 E	2.14 E	14.1 E	0.0028 R
	July 91	86.2 E	0.0182 UE	0.0025 S	710 E	181 E	0.00012 S	2.21 E	14.9 E	0.012 R
	May 92	73.6 E	0.55 E	0.0416 E	527 E	139 E	0.0002 UE	1.58 E	12.9 E	0.0227 S
LP-03	Apr 91	287 E	602 E	0.022 R	1270 E	487 E	0.00028 E	3.41 E	5.02 E	0.0028 R
	July 91	307 E	751 E	0.014 S	1480 E	598 E	0.0002 S	2.43 E	4.12 E	0.024 R
	May 92	350 E	966 E	0.0386 E	1640 E	642 E	0.0002 UE	3.58 E	0.496 US	0.125 E
	May 92(T)	307	681	0.041	2430	599	0.0002	4.36	4.09	0.06
	May 92(T)	347	951	0.0227	1620	634	0.0002	2.90	3.84	0.101
LP-04	Apr 91	6.04 E	0.0419 E	0.0086 R	223 E	1.8 E	0.0001 E	0.247 E	19.1 E	0.0028 R
	July 91	5.96 E	0.0429 US	0.0167 S	241 E	4.77 E	0.0001 R	0.344 E	18.9 E	0.0024 R
	May 92	5.91 E	0.132 UE	0.0183 E	267 E	14.3 E	0.0002 UE	0.572 E	17.9 E	0.002 UE
LP-05	Apr 91	2.91 E	0.378 E	0.0015 R	64.6 E	0.19 E	0.0001 E	0.0612 S	13.5 E	0.0028 R
	Apr 91(D)	2.89 E	0.0747 E	0.0054 R	64.2 E	0.189 E	0.0001 E	0.0536 S	13 E	0.0028 R
	July 91	2.93 E	0.0281 US	0.0096 S	70.1 E	0.106 E	0.00012 S	0.0568 E	14.3 E	0.0024 R
	July 91(D)	3.23 E	0.0212 US	0.0101 S	76.7 E	0.111 E	0.0001 R	0.0629 E	15.5 E	0.0024 R
	May 92	2.67 E	0.0763 UE	0.0132 E	63.0 E	0.0514 E	0.0002 UE	0.0557 E	12.1 E	0.002 UE
LP-06	Apr 91	0.0145 E	0.0328 E	0.002 R	17.8 E	0.0135 E	0.0001 E	0.00425 S	5.29 E	0.0028 R
	July 91	0.394 E	0.0133 US	0.00041 S	22.4 E	0.0085 US	0.0001 R	0.0354 E	5.91 E	0.0024 R
	May 92	0.01 UE	0.0176 UE	0.001 US	35.3 E	0.0171 UE	0.0002 UE	0.007 UE	3.110 UE	0.002 UE
LP-07	May 92	432 E	8.6 E	0.0606 US	2590 E	858 E	0.0002 UE	6.35 E	19.3 E	0.121 E
	May 92 (D)	436	9	0.06	2640	864	0.0002	6.88	19.4	0.131
	Aug 92	389 E	0.586 S	0.0183 E	2580 E	823 E	0.00059 E	7.13 E	20.1 E	0.124 E
	Aug 92 (T)	355	0.916	0.157	2250	808	0.0022	7.12	22.2	0.0025
	Aug 92 (T)	385	2.45	0.0273	2570	818	0.0053	7.27	20.2	0.127
LP-08	May 92	413 E	0.823 E	0.0736 E	2270 E	785 E	0.0002 E	4.50 E	23.5 E	0.147 E
	Aug 92	469 E	0.537 S	0.0848 E	2520 E	1110 E	0.0023 E	5.25 E	24.8 E	0.156 S

Appendix IIIB. Alluvial Groundwater Quality Data: Leach Pads Area.

IIIB-4

Well ID:	Sampling Dates	Cu Copper	Fe Iron	Pb Lead	Mg Magnesium	Mn Manganese	Hg Mercury	Ni Nickel	K Potassium	Ag Silver
LP-09	May 92	0.23 E	0.125 UE	0.0158 E	607 E	56.2 E	0.0002 UE	1.21 E	11.0 E	0.0089 US
	Aug 92	0.236 E	0.131 S	0.0068 E	648 E	55.3 E	0.0002 UE	1.29 E	10.6 S	0.0034 UE
LP-10	May 92	0.91 E	0.0432 UE	0.0348 E	9.85 E	0.167 E	0.0002 UE	0.0122 E	4.17 UE	0.002 UE
	Aug 92	0.907 E	0.0034 US	0.0034 E	11.4 E	0.194 E	0.0002 UE	0.0087 E	3.04 S	0.003 UE
LP-12	May 92	0.62 E	0.03 UE	0.0031 E	35.7 E	0.0182 E	0.0002 UE	0.012 E	4.86 E	0.002 UE
	Aug 92	0.674 E	0.0328 US	0.0015 E	35.1 E	0.0067 UE	0.0002 UE	0.008 UE	4.14 S	0.003 UE
LP-13	May 92	0.70 E	0.0258 UE	0.0041 E	18.6 E	0.206 E	0.0002 UE	0.0103 E	5.71 E	0.002 UE
	Aug 92	1.11 E	0.0093 US	0.0013 E	19.9 E	0.127 E	0.0002 UE	0.0145 E	4.41 S	0.003 UE
	Aug 92(D)	1.11	0.0074	0.0016	19.7	0.126	0.0002	0.0186	4.27	0.003
LP-14	May 92	0.05 E	0.045 UE	0.0016 E	45.9 E	0.006 E	0.0002 UE	0.007 UE	6.07 E	0.002 UE
	Aug 92	0.0561 E	0.0565 S	0.001 UE	57.8 E	0.0026 UE	0.0002 UE	0.008 UE	3.28 S	0.003 UE
LP-15	May 92	0.01 UE	0.0298 UE	0.0013 E	21.8 E	0.0065 E	0.0002 UE	0.007 UE	5.96 E	0.002 UE
	Aug 92	0.0062 UE	0.0246 US	0.001 UE	21.8 E	0.0033 UE	0.0002 UE	0.008 UE	7.23 UE	0.003 UE
LP-16	May 92	1.07 E	0.0502 UE	0.0043 E	60.2 E	0.021 E	0.0002 UE	0.0165 E	5.72 E	0.002 UE
	Aug 92	1.09 E	0.0598 US	0.0028 E	60.5 E	0.0059 UE	0.0002 UE	0.0189 S	7.07 UE	0.003 US

Well ID:	Sampling Dates	Na Sodium	Zn Zinc	Acidity	Alkalinity	CO ₃	HCO ₃	Cl Chloride	F Fluoride	Nitrate as N
LP-01	Apr 91	40.1 E	17.6 E	16 E	24 E			9.1 S	1.3 E	3.9 S
	July 91	37.4 E	16.3 E	26 UE	20 E			13.6 E	1.2 S	3.4 E
	May 92	36.9 E	15.3 E	62 US	20 E	20 UE	20 E	8.2 E	1.4 S	4.1 E
LP-02	Apr 91	68 E	379 E	1110 E	4 E			13.7 S	38.7 E	3 S
	July 91	69.1 E	412 E	1240 E	4.8 E			14.1 E	25.2 S	2.9 E
	May 92	61.0 E	322 E	1400 E	20 UE	20 UE	20 E	11 E	22 E	3.6 S
LP-03	Apr 91	38 E	955 E	10100 E	2.4 E			25.3 S	104 E	0 S
	July 91	38.2 E	1130 E	10900 E	4.8 E			61.6 E	430 S	0 UE
	May 92	32.4 E	1370 E	3890 E	20 UE	20 UE	20 UE	7.6 E	110 E	0.2 US
	May 92(T)	28.7	1170	11390	10	10	10	16	0.5	0.5
	May 92(T)	24.8	1350	5700	20	20	20	9.2	110	0.2
LP-04	Apr 91	86.6 E	31.5 E	28 E	40 E			9.8 S	0.83 E	0.82 S
	July 91	88.3 E	36.8 E	54 E	40 E			20.3 E	3.3 S	0.85 E
	May 92	78.5 E	57.6 E	186 US	40 E	20 UE	40 E	9.6 S	1.0 E	0.8 E
LP-05	Apr 91	40.8 E	8.52 E	10 E	20 E			9.7 S	0.86 E	3.3 S
	Apr 91(D)	40.6 E	8.51 E	12 E	16 E			9.6 S	0.91 E	3.3 S
	July 91	41.6 E	8.62 E	12 UE	16 E			13.6 E	2.5 S	3.4 E
	July 91(D)	45.2 E	9.44 E	12 UE	16 E			14.2 E	1.8 S	3.4 E
	May 92	37.7 E	8.17 E	41 US	20 UE	20 UE	20 UE	10 S	1.1 E	3.1 E
LP-06	Apr 91	153 E	0.0954 E	4.8 E	120 E			16.3 S	1 E	8.1 S
	July 91	155 E	0.43 E	4.8 UE	108 E			17.5 E	2.7 S	8.3 E
	May 92	127 E	0.0082 UE	2 UE	134 E	20 UE	134 E	17 E	0.8 S	6.8 E
LP-07	May 92	57.3 E	1770 E	10000 E	20 UE	20 UE	20 UE	6.7 E	120 S	0.3 E
	May 92(D)	64.5	1770	9420	20	20	20	6.2	120	0.2
	Aug 92	71.8 UE	1550 S	16000 S	20 UE	20 UE	20 UE	38 UE	100 E	1.0 US
	Aug 92(T)	66.7	1620	10	10	10	10	10	0.5	10.0
	Aug 92(T)	72.7	1540	7300	20	20	20	46	100	1.0
LP-08	May 92	45.0 E	1510 E	2 UE	20 UE	20 UE	20 UE	7.3 E	170 E	0.2 UE
	Aug 92	47.4 UE	1620 S	15000 S	20 UE	20 UE	20 UE	61 UE	150 E	1.0 UE

Appendix IIIB. Alluvial Groundwater Quality Data: Leach Pads Area.

IIIB-6

Well ID:	Sampling Dates	Na Sodium	Zn Zinc	Acidity	Alkalinity	CO ₃	HCO ₃	Cl Chloride	F Fluoride	Nitrate as N
LP-09	May 92	146 E	174 E	344 E	148 E	20 UE	148 E	12 E	0.6 E	4.1 E
	Aug 92	158 UE	147 S	402 S	136 E	20 UE	136 E	60 UE	0.6 E	4.8 E
LP-10	May 92	16.3 E	1.18 E	20 UE	20 UE	20 UE	20 UE	3.5 E	0.5 E	0.2 UE
	Aug 92	18 UE	1.19 S	22 S	20 UE	20 UE	20 UE	3 UE	0.6 E	0.2 E
LP-12	May 92	45.0 E	1.73 E	18 E	56 E	20 UE	56 E	30 E	0.4 E	6.5 E
	Aug 92	45.9 UE	1.62 S	39 S	59 E	20 UE	59 E	34 UE	0.4 E	6.7 E
LP-13	May 92	33.6 E	2.25 E	22 E	30 E	20 UE	30 E	15 E	0.5 E	2.3 E
	Aug 92	29.8 UE	2.69 S	32 S	20 E	20 UE	20 E	13 UE	0.4 E	2.4 E
	Aug 92(D)	29.7	2.67	36	20	20	20	13	0.4	2.3
LP-14	May 92	23.5 E	0.812 E	20 UE	36 E	20 UE	36 E	6.5 E	0.3 E	5.4 E
	Aug 92	26.7 UE	0.902 S	20 US	40 E	20 UE	40 E	7.8 UE	0.3 E	5.4 E
LP-15	May 92	27.1 E	0.673 E	20 UE	40 E	20 UE	40 E	7.1 E	0.6 E	1.6 E
	Aug 92	25.5 UE	0.684 E	20 US	36 E	20 UE	20 UE	6.9 UE	0.7 E	1.5 E
LP-16	May 92	34.7 E	3.54 E	22 E	53 E	20 UE	53 E	8.9 E	0.3 E	4.6 E
	Aug 92	25.7 UE	3.53 E	28 S	49 E	20 UE	20 UE	8.5 UE	0.3 E	4.2 E

Well ID:	Sampling Dates	Sulfate	TDS	TOC
LP-01	Apr 91	1310 E	2040 E	1.5 E
	July 91	2210 E	2140 E	1.8/1.8 E
	May 92	1400 E	2180 E	0.5 UE
LP-02	Apr 91	5160 E	7120 E	3.6 E
	July 91	6990 E	7850 E	3.0/3.3 E
	May 92	4800 E	7080 E	1.9 E
LP-03	Apr 91	26200 E	26400 E	7.9 E
	July 91	36400 E	28100 E	8.7/7.8 E
	May 92	22000 E	34000 E	6.1 E
	May 92(T)	20260	29900	7
	May 92(T)	22000	33000	6
LP-04	Apr 91	1930 E	3380 E	2.4 E
	July 91	4260 E	4060 E	3.3/3.1 S
	May 92	3100 E	4370 E	1.1 E
LP-05	Apr 91	766 E	1320 E	1.7 E
	Apr 91(D)	762 E	1260 E	1.8 US
	July 91	1700 E	1300 E	1.2/1 US
	July 91(D)	1650 E	1320 E	1.3/1 E
	May 92	810 E	1320 E	0.5 UE
LP-06	Apr 91	463 E	844 E	5.1 E
	July 91	1320 E	895 E	4.9/4.3 E
	May 92	440 E	933 E	1.4 E
LP-07	May 92	20000 E	34700 E	7.7 E
	May 92 (D)	22000	34700	7.9
	Aug 92	24000 E	31800 E	5.55 E
	Aug 92 (T)	16700	32800	8.00
	Aug 92 (T)	22000	32400	5.61
LP-08	May 92	24000 E	35100 E	8.4 E
	Aug 92	21000 E	35700 E	6.35 E

Appendix IIIB. Alluvial Groundwater Quality Data: Leach Pads Area.

IIIB-8

Well ID:	Sampling Dates	Sulfate	TDS	TOC
LP-09	May 92	3900 E	6180 E	3.1 E
	Aug 92	4100 E	6100 E	2.47 E
LP-10	May 92	160 E	320 E	0.5 UE
	Aug 92	160 E	310 UE	0.55 UE
LP-12	May 92	530 E	930 E	0.5 UE
	Aug 92	470 E	910 E	1.12 E
LP-13	May 92	310 UE	577 E	0.5 UE
	Aug 92	290 E	558 E	0.55 UE
	Aug 92(D)	290	553	0.55
LP-14	May 92	620 E	1030 E	0.5 UE
	Aug 92	670 E	1160 E	0.55 UE
LP-15	May 92	310 UE	538 E	0.5 UE
	Aug 92	290 E	548 E	0.50 US
LP-16	May 92	810	1240 E	0.5 UE
	Aug 92	790 E	1270 E	0.50 US

Notes: Concentrations in mg/l unless otherwise noted.

1. (D) = Duplicate Sample
2. 1991 Samples = Phase I
3. 1992 Samples = Phase II
4. NR = Not Reported
5. ND = Not Detected
6. (C) = degrees Celsius
7. (umhos/cm) = micromhos per centimeter
8. SU = standard pH units
9. E = enforcement quality data
10. S = screening quality data
11. R = rejected data
12. U = undetected at the concentration shown
13. (T) = triplicate samples

Source: Canonic, 1992a. Tables 7.3.1 and 7.3.2
Canonic, Jan, 1994. Tables 7.3.9 and 7.3.10

Well ID:	Dates	pH (SU)	Cd Cadmium	Cu Copper	Fe Iron	Zn Zinc	SO ₄ Sulfate
EX-2A	1970	3.82	NR	390	185	306	5895
EX-2	1969	4.45	NR	355	5	200	4310
EX-2	1969	6.88	NR	0.00	0.20	0.01	970
EX-2	1969	7.20	NR	0.00	0.30	0.01	588
EX-2	1969	8.12	NR	0.00	0.30	0.01	592
2N	1969	7.50	NR	0.02	0.50	0.02	365
AMC-1	1982-87	5.94	0.291	5.31	13.10	23.80	2062
AMC-2	1982-87	5.24	0.574	21.00	48.90	52.20	1705
AMC-3	1982-87	6.37	0.003	0.075	0.534	0.82	244
AMC-4	1982-87	6.03	0.010	0.52	0.204	2.51	360
7S	1969	7.15	NR	0.30	0.25	1.95	473
11S	1969	7.18	NR	0.01	1.25	0.19	145
AMC-8	1982-87	6.27	0.002	0.054	0.387	0.133	86.60
AMC-15	1982-87	6.64	0.002	0.015	0.610	0.159	209
AMC-25	1982-87	6.41	0.002	0.047	0.137	0.257	116

Sources:

1. Botz, M.K., and G.L. Knudson, 1970, "Hydrogeology of the Berkely Pit Area, part 1 - The Alluvium," Project 70-24, April 7.
2. U.S. Environmental Protection Agency, 1990, "Administrative Order on Consent, Remedial Investigation/Feasibility Study for Butte, Montana Area Mine Flooding Operable Unit (Silver Bow Creek/Butte Area NPL Site)," Docket No. CERCLA VIII-90-09, Attachment 4, Butte Mine Flooding Operable Unit Data Package.

Notes: Concentrations in mg/l unless otherwise noted.

1. Data for AMC wells are averages based on 9 or 10 sample events from 1982 to 1987; values below detection included at one-half the detection limit; pH values are medians.
2. Data for non-AMC wells are from one sampling event.
3. NR = Value not reported.

Well#	Date	Screened Depth (ft) or Total	Probable Aquifer	Spec. Cond umhos/cm	mg/l				
					Ca	Mg	Na	K	SO ₄
AW-1	10/06/92		Qal	284	35.5	8.9	5.5	2.6	27.6
AW-2	10/06/92			320	34.2	9.2	9.8	2.4	43.5
	dupl			320	38.3	9.9	9.9	2.6	43.9
AW-3	10/09/92			137	13	3.7	4.9	1.7	25.4
DW-103	07/24/84	55-65	Qal	350	40.8	11.2	13	6.19	84.8
(AMC-8)	07/23/85			387	54.3	14.4	12.3	3.83	105
	12/10/85			440	38	12.2	5.72	4.71	118
	12/18/85			380	47.4	11.1	12.6	3.75	127
	04/17/90			418	50.1	13.5	13.6	4.06	120
DW-111	12/06/85	15.5	Qal	851	87.1	25.5	45.3	5.4	149
(MF-11)	01/16/85			890	75.9	25	45.9	5.36	149
MF-4	11/09/89	28	Qal	1757	130	51	120	6.3	199
DW-121	01/16/85	12.1	Qal	399	42	10.1	22.6	3.7	58
(MF-1)	03/06/85			393					60
	07/25/85a			446					
	07/25/85b			446	41.9	10.9	26.8	4.7	33
	12/06/85			445	39.1	9.6	25.5	4.27	73
DW-123	01/18/85	17-37	Qal	973	100	21.8	40.1	4.7	263
GS-20	08/24/89			464	71.2	14.6	23.4	5.88	149
	11/10/89			564	67	21	27	6.8	220
	04/20/90			617	66.4	16.7	32.6	6.12	160
Botz, '69	1966-1968	13-78	Qal	283	30.9	8.81	13.2	3.29	51
Meinzer, '14	1912	5-76	Qal	TDS=148	26	6.58	6.25		7.3

Appendix IIID. Alluvial Aquifer Baseline Water Quality Data

IIID-2

Well#	Date	Cl	HCO ₃ mg/l	CO ₃	Tot Alk	Al	Sb	As
AW-1	10/06/92	2.3	142.9			7.8		1.5
AW-2	10/06/92	4.4	132.5			11.2		<1.0
	dupl	4.4	132.7			7.6		<1.0
AW-3	10/09/92	2.3	48.3			3.8		<1.0
DW-103	07/24/84	10.8			47			<5
(AMC-8)	07/23/85	14			53			<5
	12/10/85	14.5			54			<3.1
	12/18/85	12.8			56			<3.2
	04/17/90	20			50	38.5	<21.0	<0.7
DW-111	12/06/85	29			245			<6.3
(MF-11)	01/16/85	24.4			258			4.1
MF-4	11/09/89	137			473			<3.0
DW-121	01/16/85	17			100			7.4
(MF-1)	03/06/85							5.6
	07/25/85a							8
	07/25/85b				104			
	12/06/85	28.5			108			12
DW-123	01/18/85	320			221			<3.5
GS-20	08/24/89	26.9			101	11.5	<40.0	1.7
	11/10/89	29.9			133	170	<19.0	<3.0
	04/20/90	50			100	<22.0	<21.0	1.9
Botz, '69	1966-1968	6.95	93.8					
Meinzer, '14	1912	7.25	107					

Appendix IIID. Alluvial Aquifer Baseline Water Quality Data

IIID-4

Well#	Date	Ag	ug/l Tl	V	Zn	mg/l SO4	Reference
AW-1	10/06/92	<1.0		<1.0	85	27.6	7
AW-2	10/06/92 dupl	<1.0		<1.0	98	43.5	7
AW-3	10/09/92	<1.0		<1.0	58	43.9	7
DW-103 (AMC-8)	07/24/84	<1.0		<1.0	188	25.4	7
	07/23/85				101	84.8	1
	12/10/85				168	105	1
	12/18/85				148	118	2
	04/17/90	<0.1	<2.0	4.4	93	127	2
DW-111 (MF-11)	12/06/85				321	120	4
MF-4	01/16/85				<27	149	2
DW-121 (MF-1)	11/09/89				24	149	2
	01/16/85				47	199	4
	03/06/85				390	58	2
	07/25/85a				189	60	2
	07/25/85b				264		2
	12/06/85					33	2
DW-123	01/18/85				95	73	2
GS-20	08/24/89	<1.0	20	5.2	<27	263	2
	11/10/89	<0.2	<9.0	<6.0	711	149	3
	04/20/90	<0.1	<2.0	<3.0	710	220	3
Botz, '69	1966-1968				643	160	3
Meinzer, '14	1912					51	5
						7.3	6

Sources:

- 1 = MultiTech, 1987, Appendix B, Part 2, Attachment I-A and II-A.
- 2 = MultiTech, 1987, Appendix B, Part 4, Attachment VI-A and Part 2, Attachment III-A.
- 3 = CH2M Hill/Chen-Northern, 1990, Volume II, Appendix B-3 and B-4.
- 4 = CH2M Hill/Chen-Northern, 1990, Addendum, Nov. 29, 1990.
- 5 = Botz, 1969, Table 7.
- 6 = Meinzer, 1914, Table on pg. 115. Includes four wells near Butte; does not include Le Toile well or wells at Butte Reduction Works.
- 7 = MRMG, 1992 Alluvial baseline sampling data

